STUDIES ON THE HYDROGEN ION CONCENTRATION OF THE SOIL AND ITS SIGNIFICANCE TO THE VEGETATION, ESPECIALLY TO THE NATURAL DISTRIBUTION OF PLANTS.

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Introduction.

Since S. P. L. Sørensen in 1909 showed how important the hydrogen ion concentration[1]) is as a factor at the course of enzymatic processes and drew the attention of biologists to the significance which this concentration might be supposed to have for biology on the whole, numerous researches have been made on this question. I. a. can be mentioned the fine researches made by Hasselbalch (1912), Lundsgaard (1912), as also by Hasselbalch and Gammeltoft (1913) on the importance of preserving a fixed and closely limited hydrogen ion concentration in the blood of man and the higher species of animals, and the pointing out of the regulating activities by which the organism will attain this end. On the whole this question has been more thoroughly gone into by the animal physiologists, while the phyto-

[1]) By acidity (or alcalinity respectively) was in older days often meant the total quantity of acid (or base respectively) determined by titration, but the values come to at such an analysis does not need to be in any fixed relation to the hydrogen ion concentration o: the real acidity. As will be known, this is only determined by the concentration of the hydrogen ions and hydroxyl ions present and not by the non dissociated parts of the acids and the bases.

The hydrogen ion concentration of a liquid is determined by the number of hydrogen ions expressed in g found in one litre of the liquid, and the number is always expressed as a negative power of 10. Liquids which as pure distilled water contain as many hydrogen ions as hydroxyl ions are said to give a neutral reaction. As the product of the hydrogen ion and hydroxyl ion concentration in an aqueous solution at 18° is $10 \div 14.14$ (the dissociat-

physiological importance of the hydrogen ion concentration has only been examined to a small degree. In the autumn 1916 when these researches were commenced, only two larger-sized works had been puhlished on the phytophysiological domain, i. e. a dissertation by Jenny Hempel (1916) on the hydrogen ion concentration of the cellular juice of the plants, especially the succulent plants, as also the buffer action on the metabolism of the latter, and a paper by Wagner (1916) on the hydrogen ion concentration in the cellular juice of the higher plants under infection with phytopathogenous bacteria.

The object of the present researches which, as mentioned above, were commenced during the autumn 1916, has been to examine the relation of the higher plants to the hydrogen ion concentration in their natural substratum, the soil. Especially it has been the object to examine whether the hydrogen ion concentration in the soil plays a dominant part as a plant-distributing factor in Nature, and the researches, therefore, are essentially of an ecological nature.

It is likely to think that the hydrogen ion concentration may play an essential part as a plant-distributing factor. Both phytogeographists and agricultural scientists have long ago noticed that it is of great importance to the plants whether or not the soil contains a greater quantity of calcium carbonate, and that the calcium carbonate effects the different plants differently. On the other hand it has been a matter of dispute on what this effect depends, and not until of late the opinion seems to have gained ground, that it depends essentially on the action effected by the calcium carbonate on the reaction of the soil, i. e. its hydrogen ion concentration, the calcium carbonate giving an al-

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ing constant of the water) both the hydrogen ion as the hydroxyl ion concentration in pure water at this temperature is $10 \div 7.07$. It follows that if the hydrogen ion concentration of a liquid is known, the hydroxyl ion concentration will also be known; consequently it suffices to state the hydrogen ion concentration. Instead of stating the hydrogen ion concentration the logaritm with unlike sign is as a rule stated; this value, called the hydrogen ion index, is indicated as p_H, and will thus for pure distilled water be 7.07. If p_H is greater than this value, there are more hydroxyl ions than hydrogen ions in the liquid, which is said to react like a base. If p_H is smaller than 7.07, there are more hydrogen ions than hydroxyl ions, and the liquid is said to give an acid reaction. Reference is besides made to S. P. L. Sørensen (1909), Höber (1914), Michaelis (1914), and Clark (1920).

kaline reaction to the soil liquid, whereas soil not containing this substance as a rule reacts more or less like an acid.

Elder authors on the other hand entertain essentially different views as to the significance of the calcium carbonate, and on this subject there is a very elaborate literature, which will be briefly mentioned in the following.

It has long ago been noticed that certain plants, the so-called calciphilous plants, only are found on calcareous soil, i. e. soil an essential part of which is calcium carbonate, whereas other plants, the so-called calcifuge plants, or as indicated by many authors silicicolous plants never are found on calcareous soil, but only on soil not containing calcium carbonate, and the main constituent of which therefore is sand (quartz), clay, or humus. As early as 1814 Wahlenberg (1814 p. LX) has drawn the attention to the fact that certain plants exclusively are found on calcareous soil, but Unger (1836) was the first whose attention especially was drawn to the importance of the calcium carbonate to the distribution of plants; thus he gives lists of species only found on calcareous soil and of species only found on soil mainly consisting of schist, granite, or gneiss. Similar studies have been made by Schnitzlein and Frickhinger (1848), Sendtner (1854), Kerner (1863, 1869 and 1898), Nägeli (1865), Contejean (1881), and Adamović (1909). These authors, Nägeli excepted, describe the calcifuge plants as silicicolous plants, as these species most often are found on sandy soil. Schnitzlein and Frickhinger as also Sendtner are of opinion that the silicicolous plants need more silicon than the calciphilous plants, the latter more calcium than the silicicolous plants. This opinion is not shared by Kerner, who does not consider the silicicolous plants as plants needing more silicon than other plants, but on the other hand as plants that cannot develop normally when the soil contains calcium carbonate. He founds his opinion on researches showing that high-moor plants which he includes under the silicicolous plants are killed, when constantly watered with water containing calcium carbonate.

However, it gradually appeared that many plants are not as absolutely bound to one or the other form of soil as originally supposed. Thus a species which in one region only is found on calcareous soil, may in another region also be found on sandy soil (Drude 1887). That the struggle for existence with other

species also plays a part appears from the researches made by Nägeli (1865) on the appeareance of *Achillea atrata* and *A. moschata* both found in the Alps, but not always in the same area. If both species are found in a valley with both calcareous soil and slaty soil, *A. atrata* occupies the calcareous soil, *A. moschata* the slaty soil. If on the other hand only one species is found, this species will occupy both the calcareous soil and the slaty soil. Thus the species are only bound to a certain form of soil when both of them are found and thus may compete with each other for the place. When on the other hand the competition is excluded owing to only one species being found, both species can grow on both forms of soil; however, it is said that *A. moschata* will thrive worse and will be found rarer on calcareous soil than *A. atrata* on slaty soil.

In recent times American investigatores (Pipal 1916, White 1916) have made experiments with *Rumex acetosella*, which also have shown the importance of the competition to the distribution of plants. *Rumex acetosella* which is supposed to be lime-avoiding appeared to thrive best on soil containing ample quantities of calcium carbonate. The reason why the plant nevertheless is more frequently found on sandy soil is that it is coming on comparatively better here than most other plants; consequently the struggle for the place with other species will become much less sharp than on limy soil, where the plant actually would thrive best, but it will never or seldom be found here because it is supplanted by other and stronger species.

Attempts to cultivate species which in Nature either exclusively or most frequently are found on calcareous soil have in most cases shown that these species are not thriving well on soil not containing calcium carbonate, and further it has been shown that plants that in Nature never or seldom are found on calcareous soil generally are not coming on well, when cultivated on calcareous soil (Sendtner 1854, Kerner 1863, 1869, 1898, Christ 1879, Roux 1900). When lime-avoiding plants are cultivated on calcium carbonatic soil they will as a rule become chlorotic, leaves and stalks assuming a yellowish or yellowish green colour due to the defective development of the chlorophyl (Gris 1845, Fliche and Grandeau 1873, 1874, Luedecke 1892, 1893, Roux 1900, Dauthenay 1901, Guillon 1895, Guillon and Brunaud 1903, Hilgard 1906, Molz 1908,

Rivière and Bailhache 1910, Pfeiffer and Blanck 1911, Gile 1911, Gile and Ageton 1914, Gile and Carrero 1917, Creydt 1915). Fliche and Grandeau (1873, 1874) thought that the reason of the so-called lime chlorosis was the want of potassium, as they found that chlorotic individuals of the calcifuge trees *Pinus pinaster* and *Castanea vesca* which they had cultivated on calcareous soil, contained much less potassium than normal not chlorotic individuals. Büsgen (1914), however, has substantiated that calcifuge plants as a rule do not suffer from want of potassium when cultivated on calcareous soil. Büsgen found that chlorotic individuals of *Sarothamnus scoparius*, *Calluna vulgaris* and *Digitalis purpurea* cultivated on calcareous soil did not contain less potassium than normal individuals cultivated on sandy soil. The same observations have been made by Gile (Gile 1911, Gile and Ageton 1914, Gile and Carrero 1917) with regard to *Oryza sativa*, *Saccharum officinarum* and *Ananas sativus*.

The reason of the lime chlorosis seems on the other hand, according to researches made by most investigators, to be want of iron, as it appears that chlorotic individuals of lime-avoiding plants, which have been cultivated on calcareous soil contain less iron than normal, not chlorotic individuals of the same species (Schimper 1898, Gile 1911, Gile and Carrero 1917, Gile and Ageton 1914), and that chlorotic individuals may be cured by repeated hosings of the plants with solutions of ferric salts (Gris 1845, Sachs 1888, Guillon 1895, Hiltner 1909, 1911, 1915, Gile 1911, Gile and Carrero 1917, 1920).

Thus it seems to be evident from the researches made by the said investigators, that the lime-avoiding plants have difficulties in absorbing iron on calcareous soil, where iron is found in almost undissolved condition. However, it does not appear from these researches why the calciphilous plants do not suffer from want of iron on calcareous soil, and the researches have shown that calciphilous plants as a rule do not contain less iron than the lime-avoiding plants. The latter thus cannot be considered as plants needing more iron than the lime plants. The studies made on the nature of the chlorosis, therefore, do not explain why the different plants react differently towards calcium carbonate.

Different opinions have been put forward with regard to this

question. That the view taken by the elder phytogeographists that the calciphilous plants need more calcium than the calcifuge species and the latter more silicon than the former is incorrect, has been proved by Hoffmann (1865) and Fliche and Grandeau (1879) who have shown that calciphilous plants as a rule do not contain more calcium than the lime-avoiding ones, nor that the latter in general contain more silicon than the calciphilous plants. It also appeared that calciphilous plants do not thrive on a non-calcium carbonatic soil, even if calcium sulphate is added to the soil (Hartwell and Damon 1914). Thus calcium sulphate has not the same effect as calcium carbonate, and this is indicative that it is not the content of calcium that matters but, on the other hand, the content of carbonate.

A number of investigators have been of opinion that it is not the chemical qualities of the calcium carbonate, but its physical ones that are of vital importance to the plants, e. g. Thurmann (1849) who states that the calcium carbonate gives the soil certain physical qualities, i. a. calcareous soil will easily become dry. Therefore he describes the calciphilous plants as xerophytes and the calcifuge plants (siliciculous plants) as hygrophytes, as he thinks that sandy soil in most cases is moist soil. Of latter-day authors Hoffmann (1871), Drude (1887) and Kraus (1911) virtually adhere to this theory.

Of late Truog (Truog 1918, Truog and Meacham 1919, Parker and Truog 1920) have advanced the theory that the calciphilous plants need more calcium carbonate than the calcifuge plants. He supposes that the calciphilous plants have a more active metabolism than the calcifuge ones, and that considerable quantities of acid is formed in the cellular juice at the metabolic process. To neutralize these acids the plants use calcium carbonate, and as the calciphilous plants have a more active metabolism than the calcifuge species, the latter need more calcium carbonate than the former.

Finally, as mentioned above, the stress has — especially in the science of agriculture — been laid on the alkaline reaction given to the soil by the calcium carbonate. One of the first authors who considers the "lime question" as a question of the reaction of the soil, is Ravn (Christensen, Harder and Ravn 1909). He describes the calciphilous plants as plants that are coming on best when the soil gives an alkaline reaction, the calcifuge

plants as species which are thriving best on acid soil; he therefore proposes the designation "calciphilous plants" replaced by "base loving plants" or "basic soil plants" and the designation "calcifuge plants" by "base shy plants" or "acid soil plants". Ravn and later Ferdinandsen (1918) have divided the field weeds — according to their being found most frequently on acid or alkaline-reacting soil, — in acid soil plants and basic soil plants; for the researches of the reaction of the soil they have used both litmus solution and the azotobacter test [1]) introduced by Christensen (1906), Christensen and Larsen (1910).

In phytogeography, studies on the calcifuge moss species *Sphagnum* have lead to the result that the calcifuge nature of

[1]) The azotobacter test does not in reality give any expression of the reaction of the soil, far less of its hydrogen ion concentration. This test is made in the following way.

A certain quantity of the soil which is to be examined is placed in a flask containing a solution of mannite and secondary calcium phosphate; then it is inoculated with a raw culture of the bacterium *azobacter*. If, after having stood for some time the *azobacter* forms a cohesive membrane on the surface of the liquid, the soil is described as "not needy of lime". If the membrane is not formed the soil is on the other hand described as "needy of lime".

When the sample has been placed in the flask, an active formation of acid takes place in the solution (Bondorff 1918). Whether the *azobacter* membrane is then formed depends on the concentration of hydrogen ions of the liquid not exceeding a value corresponding to 6,7 in p_H, as *azotobacter* only develops, if the hydrogen ion concentration does not reach the critical value (Bondorff 1918). This again depends partly on the basic quantity of the sample, partly on the acid quantity formed by the bacteria. The latter quantity is hardly the same in all cases, as the acid quantity formed surely is effected by accidental circumstances. The objection may of course be raised that the acid quantity formed shall not be the same in all cases, as it has to correspond to the production of acid which under natural conditions takes place in the soil, and which certainly differs as regards the different soils. The *azotobacter* test has then to prove whether a sufficient basic quantity corresponding to an acid production in the soil is found or not. It must be remembered that the conditions of the nutritient liquids are quite different from those in the natural soil and very favourable to the acid producing bacteria, and it is very improbable that what takes place in the nutrient liquids is in any relation to what takes place in the soil under natural conditions. Thus the nitrificating bacteria often act quite otherwise in nutrient liquids than in the soil (vide e. g. Hesselmann 1917, p. 320).

It will appear from what has been developed that the *azobacter* test cannot throw light on the concentration of hydrogen ions in the soil nor, as is maintained by Bondorff (1918), elucidate anything on its buffer content (vide foodnote p. 26).

these mosses is due to the fact that they cannot develop in other liquids than such as give an acid reaction, while they are killed by such as have an alkaline reaction, e. g. by calcium carbonatic water (Paul 1906, 1908, Skene 1915). Solutions of calcium sulphate are on the other hand harmless to these mosses (Poul 1906). That calcium carbonate as also basic substances on the whole have a killing effect on *Sphagnum* plants is due to the fact that the acid[1]) slightly soluble found in the cellular walls of these mosses is neutralized, which involves the death of the plants (Leiningen 1907, Paul 1908).

That the reaction of the culture medium also plays a part as regards other mosses appears from the researches made by Kessler (1914) on the germination of moss spores in liquids, which give an acid, neutral, or alcaline reaction. These researches showed that spores of mosses from acid soil, e. g. from high moors or from raw humus only were germinating in an acid liquid, the spores of the calciphilous mosses only in an alkaline one. The researches only concerned the germination itself, which was controlled microscopically.

As regards the higher plants there have — apart from the above mentioned studies on weeds — only been made few researches on their relation to the reaction of the soil. Chodat (1915) drew the conclusion, based upon researches made with the calcifuge species *Digitalis purpurea*, that the defective ability of this plant to develop on calcareous soil is due to the fact that it cannot thrive in alkaline soil as not only calcium carbonate, but also other substances which have an alkine reaction check the growth of this plant when mixed with the soil.

While studying the appearance of *Molinia coerulea* and *Eriophorum vaginatum* in the English moors, Jefferies (1915) found that *Eriophorum* always is found on more acid soil than *Molinia* (the "acidity" of the soil was determined by titration).

[1]) Baumann and Gully (1910) hold that *sphagnum* plants do not contain any acid, but that the acid reaction is produced by the colloid cellular membranes adsorbing the bases of neutral salts and thus liberating the acids. It is these acids which give the acid reaction, while the membranes themselves originally do not contain any acid. Their theory also includes the humus substances, which they do not either consider as acids. Baumann and Gully's colloid chemical theory has, however, proved to be incorrect, as Odén (1919 p. 140) has shown that neither *sphagnum* plants nor humus are able to decompose neutral salts.

Furthermore after the beginning of the researches published in this treatise, Wherry, an American author (1918) published an essay on an examination of the habitats of 40 orchids with regard to the concentration of hydrogen ions in the soil. He came to the conclusion that some species (the calciphilous plants) only grow on soil giving a neutral or an alkaline reaction (p_H 7—8), others only on strongly acid soil (p_H 4—5), others again only on less acid soil, while some few species were not bound to soils with a narrowly limited hydrogen ion concentration[1]). Wherry has later (1920 II) in the same way and with similar results examined the habitats of the halophytes. An earlier treatise by Wherry (1916) deals with the habitats of the fern species *Camptosorus rhizophyllus*. This species which is supposed to be calciphilous appeared however not at all to be exclusively bound to a soil giving a neutral or an alkaline reaction.

It may finally be mentioned that also Arrhenius (1920) has measured the hydrogen ions in soil taken from the habitats of some Swedish formations. He found that the concentration of hydrogen ions in soil within the same formation lies within fixed ranges of hydrogen ion concentration more or less narrowly limited.

From the above literature it will appear that there is every probability that the concentration of hydrogen ion in the soil plays an essential part as a plant distributing factor in Nature, and the object of the researches published in the present treatise has, as mentioned before, been to examine what significance might be attached to the concentration of hydrogen ions in the soil in the said respect.

In order to examine this question, I have by aid of Raunkjær's formation-statistical method made a number of researches of the composition of natural Danish plant formations[2]). Simultaneously I have drawn samples of soil on the habitats, the hydrogen ion concentration of which was determined. By comparing the analysis of the botanical formations with the physico-chemi-

[1]) The value of Wherry's investigations is partly deteriorated owing to the procedure used at the determination of the hydrogen ion concentration (vide p. 23).

[2]) The word "formation" is in this treatise used to designate the smallest phytogeographical unity; all plant communities the specific composition and appearance of which are essentially alike and the dominating species of which are the same belong to the same formation.

cal soil analysis there appeared — as will be shown later — on an immediate view to be a rather fixed law-directed relation between the composition of the vegetation and the concentration of hydrogen ions in the soil, as essential variations in the latter always are accompanied by variations in the composition of the vegetation, also provided the other conditions were alike, while habitats with nearly the same concentration of hydrogen ions and the same conditions of light and moisture have approximately the same vegetation. By statistical treatment of the material it furthermore appeared that the single species only are found on soil the hydrogen ion concentration of which lies within a fixed range of hydrogen ion concentration, different for each single species.

However, it was not my sole object to substantiate this, but also to examine whether it is the hydrogen ion concentration as such which determines the plant distribution as it has been shown. For it may be a question partly of direct, partly of indirect actions of the hydrogen ion concentration. In case the concentration of hydrogen ions in the soil in a number of habitats varies regularly with the composition of the vegetation, the different plants will thrive best at hydrogen ion concentrations different for the different species, if it is the hydrogen ion concentration which is the direct reason of the plant distribution. To examine whether this was the case, I have made experiments with water cultures of different species, these species being cultivated in solutions of different hydrogen ion concentration under conditions which were otherwise homogeneous.

As it is, it may also be a question of indirect actions of the concentration of hydrogen ions. Thus it is a well-known matter that the concentration of hydrogen ions in the soil (reaction) exercices a rather great influence on its microorganic life and the transformation processes (Bear 1917, Noyes and Conner 1919, H. Fischer 1909, Potter and Snyder 1917). It is especially the influence which the reaction of the soil exercices on the course of the transformation processes of the nitrogen which may be supposed to play a part at the plant distribution, for of all the substances the transformation of which depends on the activity of the microorganisms only nitrogen is of importance to the higher plants. It has in many cases been substantiated that nitrification does not take place in strongly acid soils, and

that the nitrification is highly furthered when calcium carbonate or other substances, reacting like an alkaly are mixed with a soil originally not giving a neutral or alkaline reaction (Lemmermann, Fischer and Husek 1909, Behrend 1881, Noyes and Conner 1919, Bear 1917). Bear is of opinion that when calciphilous plants do not thrive on strongly acid soils, it is due to these plants not standing very acid reaction, but on the other hand they demand the nitrogen in the form of nitrate and cannot make use of ammonia nitrogen, which as contrasted to nitrate nitrogen is found in ample quantities in strongly acid soils. On the other hand plants thriving on strongly acid soils can make use of ammonia nitrogen. According to Bear, lime-loving plants = nitrate plants, lime-avoiding plants = ammonia plants. Similar opinions are met with in the forestal literature. Thus Müller (1918) holds that the special qualities of the raw humus and heath soil, which are unfavourable to the wood vegetation are not due to the strongly acid reaction of these soils, but to the absent or highly restrictive nitrification. Hesselmann, the Swedish investigator (1917) who attaches great weight to the significance of nitrification for the plant distribution, entertains nearly the same view. He too considers the plants found on strongly acid, therefore not nitrificating soils as plants which can make use of ammonia nitrogen, while the plants found on less acid, neutral, or alkaline soils are such as demand nitrate as the source of nitrogen.

In order to examine whether the more or less complete transformation of the nitrogen is of importance to the plant distribution, I have taken samples on some habitats of the formations investigated to examine the course of the forming of ammonia and that of the nitrification. I have also made experiments on the possible different value of ammonia nitrogen and nitrate nitrogen as source of nitrogen for the different plants; for these experiments I have partly used plants exclusively found on strongly acid not nitrificating soil, partly plants exclusively found on soil giving poor acid, neutral or basic reaction, the nitrification as a rule being most active in such soils.

Another indirect action of the concentration of hydrogen ions in the soil upon which the stress also has been laid, is the influence exercised by the hydrogen ion concentration on the solubility of aluminum, as small quantities of aluminum in solution

may be found in acid soils (Abbott, Conner and Smalley 1913, Ruprecht and Morse 1917, Kappen 1916, 1917). Hartwell and Pember (1918, 1919) hold that this is the reason of lime-loving plants not thriving on strongly acid soils, as aluminum compounds even in small quantities are said to be toxic to them, whereas lime-avoiding plants are not or only to a small degree injured by aluminum compounds in solution. The theory has been advanced on the basis of water culture experiments with rye *(Secale cereale)* and barley *(Hordeum distichum)*, which showed that aluminum compounds are toxic to the lime-loving plant barley, while rye which thrives comparatively well on strongly acid soil, is almost entirely unsuscepstible hereof. According to the two authors the concentration of hydrogen ions in the soil does not play any direct part, as they are of opinion that barley can stand as high concentration of hydrogen ions as rye.

In order to test this theory and thus examine whether aluminum is more toxic to lime-loving plants than to lime-avoiding plants, I have made some water culture experiments partly with lime-loving plants, partly with lime-avoiding plants.

A third indirect action of the concentration of hydrogen ions in the soil, which may be supposed to bear a part as regards plant distribution, is the influence exerciced by the concentration of hydrogen ions on the contents of natural plant nutrients of the soil, as some nutrients in acid soil easily will desolve and gradually be washed out. Therefore, acid soils are often poorer on mineral plant nutrients than neutral and alkaline ones (Hoagland 1917, p. 557).

I have in order also to have my attention directed to the possible significance which this may have on plant distribution determined, as regards some of the examined habitats, the contents of easily soluble mineral plant-nutrients of the soil.

Furthermore it may be possible that the plants in Nature gradually not only form the hydrogen ion concentration most favourable to them, but on the whole form the soil condition most favourable to themselves. The composition of the vegetation would in this case become the primary, the concentration of hydrogen ions the secondary. However, I want to observe that this is highly improbable, as all agricultural experience decidedly tells against it. In case this theory was correct it would

be most paying year after year to cultivate the same species on the same soil, but as is well-known, this very procedure has proved unprofitable, consequently everywhere rotation is now used. It is very probable that the single species change the conditions of the soil in a direction unfavourable to themselves. In order to try whether the plants themselves are able to form a concentration of hydrogen ions favourable to themselves, I have made experiments with a view to examining whether the plants are able to modify the concentration of hydrogen ions of a culture medium, and this being the case whether the modifications take place in a direction favourable to the plants and whether the different species change the concentration of hydrogen ions to different values.

As will appear from the above, my investigations comprehend both analysis of formations and their habitats as culture experiments. It will, therefore, answer the purpose in the first section (A) to mention the habitats and their vegetation and in the second section (B) to mention the experiments.

A. THE HYDROGEN ION CONCENTRATION OF THE SOIL AND THE DISTRIBUTION OF THE SPECIES (FORMATIONS).

Methodics of the Research.

Selection of objects experimented on. The researches comprise meadow and wood-ground formations as also some formations on open mineral soil.

For the investigations I have as far as possible selected such formations as might be supposed to be in biological equilibrium with the conditions given at the moment ɔ: formations the composition of which is comparatively constant as long as the conditions are not changed. To bring about this it is not at all necessary, that the formations shall not be affected by cultural intrenchement. Thus the meadow formations are highly affected by human activity, as they are exposed to cutting, but this has been the case through many years, and consequently the vegetation has had time to adapt itself to the conditions created by

the cutting. While the meadow formations may be said to be in comparative equilibrium with the conditions given at the moment, this only to a smaller degree applies to the wood-ground formations. The reason hereof is mainly that the conditions of light in the wood-ground owing to fellings constantly being made very seldom is the same for a number of years. Therefore the wood-ground vegetation does not get time to adapt itself to the given conditions of light, before they change again. For this reason the wood-ground formations examined have as far as possible been selected in places, where it might be supposed that fellings have not been made of late years.

Furthermore stress has been laid upon the single formations examined being severally homogeneous, and therefore it was necessary only to examine small areas, in most cases areas of only a few square metres. This also was made in view of selecting soil samples for examination, as it was not considered correct to allow the analysis to "pass" for too great areas.

The formation-statistical method. When making researches as the present ones, it is of great importance to determine the frequency of the species, as the degree of frequency must be considered as implying the ability of the plants to assert themselves under the given conditions, so that a greater frequency in one species indicates a greater ability in the species to stand the ground at the given habitats than a less frequency. Therefore, as has been mentioned before, Raunkjær's formation-statistical method[1]) has been used at the botanical analysis of the formations. Only the frequency of the species (percentage) has been determined and owing to the small areas examined, only 10 trial areas have been selected in each locality.

The determination of the hydrogen ion concentration of the soil samples. In a depth of about 10 cm. samples of the soil were taken on each of the habitats examined, as a rule two or three in each locality. These two or three samples were mixed at the spot and cleared of pebbles, sticks and the like. These samples were carried home in a glass holding about

[1]) When using this method a number of trial areas, each of 0.1 m^2 are selected of the formation which is to be examined. By stating for each species the percentage in which it is found in the selected trial areas, figures are come at which express the frequency of the species in the formation. See further Raunkjær 1909, 1916, 1918.

70 cc of soil. The samples were transferred to beakers and 70 cc of destilled water added; they were allowed to stand for about 24 hours, repeated stirrings being made during this time with a glass spatula. After the lapse of the 24 hours the hydrogen ion concentration was measured. For the determination hereof I have partly used the electrometric method, partly the colorimetric one.

The electrometric method was executed according to S. P. L. Sørensen (1909). For an electrode vessel I have used the apparatus designed by Hasselbalch (1911), as the carbonic acid when using this apparatus is not driven off from the liquids, as was the case at the original measurements. The soil extracts which were measured electrometrically were produced by pouring the soil depositions through a china strainer the holes of which were hardly one mm in diametre. Thus the coarsest particles were removed, as otherwise particles might choke the glass tubes of the electrode vessel and the perforations of the stop-cock. The soil extract thus strained was introduced into the electrode vessel and the measurement took place in the ordinary way.

The measurements do not occasion special difficulties apart from the fact that owing to the small electrical conductive power of the liquid only small turns of the quicksilver column of the capillary electrometre are obtained, and therefore it is not possible to measure with as great exactitude as is otherwise the case. For this reason I have only measured to one decimal place when giving p_H values, as only this place might be accurately determined. Besides a determination of p_H with an exactitude of $\pm$ 0,1 is quite sufficient when measuring the concentration of hydrogen ions of the soil extract.

The colorimetric method, elaborated and described by S. P. L. Sørensen (1909) distinguishes itself in contradiction to the electrometric one by its great simplicity, as very few apparatuses are required. It is extremely quick and easy to work, and because it is especially adapted to measurements of soil extracts, it will briefly be described here.

At this method indicators are used for the determination of the concentration of hydrogen ions. An indicator is a substance which in liquids of different hydrogen ion concentration — which, however, must lie within a certain range of hydrogen ion concentration, fixed for each indicator ("the range" of the indicator)

— assumes different colours or tones. The concentration of hydrogen ions of a liquid may be determined by aid of an indicator in the following way, the concentration of hydrogen ions lying within the range of the indicator.

A number of standard solutions (liquids of comparison), the hydrogen ion concentration of which is known and varies with fixed intervals (e. g. with a reciprocal difference of 0,2 in p_H) over the range of the indicator are measured in test tubes, equal volumes of liquid being placed in each test tube. The same volume of the liquid the hydrogen ion concentration of which is to be measured is also introduced into the test tube. Equal quantities (a few drops) of the indicator solution are then added to each test tube. The colours of the standard solution will then form a colour scale, in which the liquid the hydrogen ion concentration of which is to be determined may be ranged, and the latter will then have the same hydrogen ion concentration as the standard solution the coulour and tone of which are the same. The standard solution and their preparation have been described in the work published by S. P. L. Sørensen in 1909.

When using the colorimetric method for the determination of the hydrogen ion concentration of the soil extract it is of course necessary to filter the soil extracts, and it appeared necessary for this purpose to use washed filters, such filters of course not containing any acid at all. The Swedish Berzelius filters proved excellent in this respect, and consequently I have always used them. Furthermore it appeared to be necessary to filter the soil extracts quite clear. This was most easily obtained by transferring as much as possible of the solid soil to the filter. If the soil extract is not filtered absolutely clear, the measurement will give wrong results, which is due to the fact that the indicator is absorbed by the particles floating in the liquid. In order to avoid that a possible adsorbtion might affect the hydrogen ion concentration of the extract, the filtrate first run through was not used at the measurements.

The clear soil extracts are often brownish or yellowish from the organic substances in solution which render the comparison of the tone of the indicator in the soil extract with its colour-tone in the different standard solutions difficult, in many cases even impossible. This difficulty, however, was easily surmounted

when making the comparison in a comparator, the construction of which will be seen from the following figure.

In the first row the test tubes with the standard solutions are placed to which the indicator solution is added; in this row is also placed a test tube containing the soil extract, the hydrogen ion concentration of which is to be determined to which is also added the indicator solution. In the second row a test tube containing the soil extract but without the indicator solution is placed behind each of the standard solutions. Behind the test tube in the first row which contains soil extract + indicator a test tube is placed containing distilled water. If the standard solutions are now looked at through the "window" cut in the foremost vertical wall of the support the different colours of the indicator in the different standard solutions will be seen against the colour of the soil extracts, the confusing effect of which during the measurements thus is eliminated; consequently it will be easy to range the test tubes containing soil extract + indicator in its proper place in the colour scale. When using this procedure it is possible to determine a concentration of hydrogen ions of the soil extract of any colour whatever. As the soil extracts always are at least slightly brown coloured the comparator has been used at all the measurements; besides, it ought always to be used when making colorimetric measurements of the concentration of hydrogen ions of the soil extract. It is amatter of course that the test tubes must be colourless, of the same thickness and all provided with equal volumes of liquid. The test tubes used by me were 14 mm in external diametre and about 13 cm high, 4 cc of liquid were used in each glass.

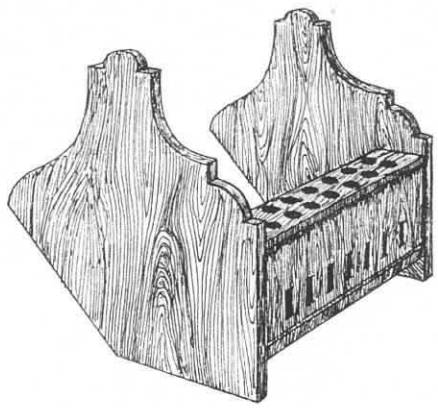


Fig. 1. Comparator.

It was combined with the greatest difficulty to find suitable indicators, as it quickly appeared that far the greater part of all known indicators were inapplicable, as wrong results, i. e. results

not in conformity with the electrometric measurements, are reached. Thus all the indicators mentioned by S. P. L. Sørensen in 1909 which owing to the position of the change range might he considered, proved to be inapplicable as errors of up to 2.0 in p_H were reached when using them. The reason hereof is supposed to be that these indicators combine with the substances found in the soil extract or are decomposed by them. In many cases the indicator is completely decolorized by the soil extract. This e. g. holds good of litmus which in many soil extracts assumes a yellow or yellowish red colour[1]). Only one of the indicators at hand at the Carlsberg Laboratory in 1916 proved suitable, i. e. naphtol-phtalein, described by S. P. L. Sørensen and Palizsch (1910). American investigators (Gillespie 1916, Gillespie and Wise 1918) have also substantiated that most of the existing indicators are inapplicable for the determination of the concentration of hydrogen ions in the soil extracts. Gillespie (1916), however, found that a number of indicators prepared by Lubs and Clark (1915) were suitable. Not until I have had these indicators ordered from America I succeeded in obtaining satisfactory results by aid of the colorimetric method.

I have made use of 4 indicators at the colorimetric measurements; their names, colour change and range will appear from the following tabular survey (table 1).

The three first mentioned indicators originally prepared and described by Lubs and Clark (1915; see also Clark and Lubs 1917) were used in alcoholic solutions, prepared by dissolving 0.4 g of the indicator in one litre of 93 per cent alcohol; 0.4 g of naphtol-phthalein was dissolved in 600 cc of 93 per cent alcohol, then 400 cc of water were added. Two drops of the solutions of bromfenolblue and bromcresolpurple were used for each test tube at the measurements, three drops of the bromtymolblue solution and finally 5 drops of the naphtol-phthalein solution. The

[1]) Christensen and Larsen (1910) describe soil samples as very acid when giving a litmus solution a yellowish red colour. As is well known a litmus solution will never turn yellowish red when adding hydrochloric acid but only red. A clay soil sample examined by me assumed when adding litmus solution a yellowish red colour; at an electrometric measurement the hydrogen ion concentration of this extract was found to be 6.7 expressed in p_H. Thus it appears that nearly neutral soils may easily at the litmus test be described as "very acid".

Table 1.

Chemical name	Common name	Colour change	Range p_H
Tetra-bromo-phenol-sulfon-phthalein	Brom-fenol-blue	yellow-blue	3.0—4.8
Dibromo-orto-cresol-sulfon-phthalein	Brom-cresol-purple	yellow-purple	4.8—6.8
Dibromo-thymol-sulfon-phthalein	Brom-tymol-blue	yellow-blue	6.0—7.6
α-Naphtol-phthalein	Naphtol-phthalein	light reddish-green	7.2—8.7

standard solution used at the measurements were those generally used at the Carlsberg Laboratory (vide S. P. L. Sørensen 1909).

At the measurements of the soil extracts I have made use of altogether 13 different standard solutions, each of which had the following p_H value: 3.2 : 3.6 : 4.0 : 4.4 : 4.8 : 5.2 : 5.6 : 6.0 : 6.4 : 6.8 : 7.2 : 7.6 and 8.0. By the aid of four indicators four different colour scales were laid down, the bromfenolblue being used in the range 3.2—4.8 bromcresolpurple in the range 4.8—6.4, bromthymolblue in the range 6.0—7.6 and finally naphtol-phthalein in the range 7.2—8.0. As will be seen, the range of the two above mentioned indicators do not interfere with one another. Therefore, it was not quite easy to determine the concentration of hydrogen ions of a soil extract having a p_H value in the vicinity of 4.8. After some time, however, I succeeded in determining the hydrogen ion concentration in the extracts with sufficient exactitude in this range, but only if both indicators were tried. In the said difficult range (near p_H 4.8) American investigators make use of methyl red (vide Gillespie 1916), but when using this indicator I have come to wrong results, as methyl red just as litmus is decolorized in many soil extracts, especially in those taken from very humic soils.

As appears from the above, the series of standard liquids used had a difference of 0.4 in p_H as regards the concentration of hydrogen ions. If it was thought that an extract with added indicator had its proper place in the colour scale between two subsequent standard liquide, it was given the p_H value 4.2, if the tone was e. g. between that of the two standard liquids the p_H of which was 4.0 and 4.4 respectively. If on the other hand its tone was nearer to that of the standard liquid the p_H value

of which was 4.0, it was given the p_H value 4.1 e. t. c. In this way it was possible with comparative exactitude to discern between differences of 0.1 in p_H. Furthermore it must be stated that all colorimetric measurements have been executed by day, and that the standard solutions in the test tubes to which the indicator was added only were used the day on which they were prepared. This was necessary, as three out of the four indicators are not durable in the standard solutions; bromfenolblue is the least durable, as its colour-tone in the standard solutions quickly will increase when standing for some time. It may even be necessary to renew the standard liquids containing this indicator several times in the course of the same day. Bromcresolpurple and bromthymolblue on the other hand are bleached when standing for same time, while bromthymolblue seems to be rather durable. The alcoholic indicator solutions will on the contrary last a long time.

Sometimes it may occur that one p_H value is reached for a given soil extract when using bromcresolpurple, another value when bromfenolblue is used. It is e. g. sometimes found that soil extracts measured with bromcresolpurple has a tone lying between that of the two standard liquids, the p_H of which is 4.8 and 5.2 respectively, while it has been found when bromfenolblue is used, that the soil extract has a tone lying between that of the two standard liquids, the p_H of which is 4.4 and 4.8 respectively. In this case it has always appeared that the p_H value indicated by bromcresolpurple is in nearest conformity with the p_H value found by electrometric measurements. At colorimetric measurements bromcresolpurple ought always to be the first indicator tried. This is besides also practical from the reason that in case the p_H value of the soil extract does not lie within the change point of this indicator, it is known at once whether bromfenolblue or bromthymolblue is to be used. Using naphthol-phtalein which is rarely used, a p_H value will sometimes be come at, which is lower than the p_H value reached by the aid of bromthymolblue. In this case it has always appeared that the p_H value reached by aid of bromthymolblue is in closer conformity wirh the electrometrically measured value than the p_H value reached by aid of naphtol-phtalein.

Comparison between the results of the electrometric method and those of the colorimetric one. When the colori-

metric measurements are executed with careful observation of the rules laid down here, sufficiently exact results, i. e. results conformable to the electrometric measurements are reached. The conformity between the results of the methods will appear from table 2, in which the p_H values for a number of soil extracts measured by aid of both methods are stated. The measurements comprise both peaty soils and mineral soils. In the table only few of the soil sample analysis are stated, which have been carried out by aid of both methods. Thus the soil samples from all the meadow examined have been measured by both methods. On account of lack of space only the results of 18 double analysis are given, selected at hazard.

It will appear from the table that I have never substantiated greater difference than 0.2 between the results of the two methods as regards the meadow soil and wood soil mentioned in this treatise[1]). Furthermore it will be seen that the colorimetric method, provided it does not give the same p_H value as the electrometric one, in most cases will give a somewhat lower p_H value.

If the above rules for the application of the colorimetric method on soil extracts are not observed, p_H values will be reached which deviate considerably from those found by aid of the electrometric method. If essentially more than two drops of the bromfenolblue and bromcresolpurple solutions are used at the measurements, p_H values will be reached for the soil extracts which are too low, because the two said indicators are acids. Of the other two indicators more solution may be used, as this has not proved to affect the result. If the soil extracts are not filtered absolutely clear, too low p_H values will be reached[2]).

Gillespie (1916) who has measured the hydrogen ion concentration of soil extracts both electrometrically and colorimetrically, has found similar conformity — though not so good — between the results of the two methods as indicated above. Besides the following investigators have made determinations of

[1]) As regards arables I have found greater deviations; the difference might here sometime amount to 0.5 in the p_H value.

[2]) When executing the litmus test a neutral salt, e. g. magnesium sulphate is often added to the soil precipitate in order that the extract might more easily be made clear (see Christensen and Larsen 1910 p. 431). This, however, might bring about an increase of the hydrogen ion concentration and therefore cannot be permitted.

Table 2.

(The numbers of the localities refer to the tables 4—12 and 18—26).

Number of locality	p_H electrometric	p_H colorimetric	Difference
80	3.5	3.5	0
4	3.9	3.8	0.1
104	4.2	4.1	0.1
12	4.4	4.4	0
18	4.7	4.7	0
126	4.7	4.6	0.1
152	5.2	5.0	0.2
26	5.4	5.3	0.1
178	5.6	5.6	0
39	5.7	5.7	0
46	6.2	6.0	0.2
211	6.4	6.4	0
58	6.7	6.7	0
228	6.8	6.7	0.1
67	7.2	7.3	± 0.1
241	7.2	7.2	0
76	7.8	7.7	0.1
266	7.9	7.8	0.1

the hydrogen ion concentration of soil extracts: Saidel (1913), G. Fischer (1914), Kappen (1916, 1917, 1920), Kappen and Zapfe (1917), Gillespie (1916, 1920), Gillespie and Wise (1918), Gillespie and Hurst (1917, 1918), Wherry (1916, 1918, 1919, 1920), Sharp and Hoagland (1916, 1919), Hoagland and Sharp (1918), Hoagland and Christie (1918), Plummer (1918), Morse (1918), Olsen (1918), Odén (1919), Lipman (1919), Joffe (1920), Blair and Prince (1920), Martin (1920) and Arrhenius (1920)[1]). The methods of these investigators do

[1]) Wherry's and Arrhenius' investigations have been mentioned in the introduction. The investigations made by the other investigators deal partly with the physical-chemical relation of the humus substances, partly with the influence of the fertilizers on the hydrogen ion concentration of the arable soils, partly with the appearance of potato scab and other similar subjects disconnected with the subject of this treatise. Therefore, they will not be mentioned further here.

not essentially differ from those employed by me. The procedure used by Wherry is the only one that will be more fully entered upon.

As mentioned in the introduction, Wherry has made researches on the concentration of hydrogen ions in the soil on the habitats of American orchids. He used the colorimetric method, and as the determinations were made in the field he had to simplify the method. Besides he has in a special paper in details described the procedure followed by him. He did not extract the soil with distilled water, but with water found in Nature (spring water, river water, or sea water) which, as will be known, in many cases can be very calcareous. After having shaken soil and water in a glass, he allowed this to remain untouched for a few minutes in order that the soil may have time to settle; then the liquid was poured out. He did not filter this liquid which in most cases certainly must have been very turbid, in a few cases even intransparent, but he directly added a similar volume of the indicator solution. He did not use standard solutions, but he only observed the colour of the indicator in the soil extract. Then he roughly stated the concentration of hydrogen ions. Wherry (1920) states that he intends further to simplify the method. It cannot be denied that the procedure followed by him is extremely simple, but the results reached in this way are in return less valuable. By using Wherry's procedure I have substantiated errors of up to 2 in p_H. The fact that the soil extracts are not filtered is the essential reason of the errors, which might occur when using this procedure. The error is especially great as regards the more acid extracts, while the errors only are small as regards the neutral or basic extracts.

The significance of carbonic acid on the concentration of hydrogen ions of the soil extracts. By means of the colorimetric method I have examined how great is the significance of carbonic acid in the soil extracts on the concentration of hydrogen ions. It appeared at these investigations that the concentration of hydrogen ions in the soil extracts decreases, when the carbonic acid is driven off by conducting air not containing carbonic acid through the soil; this, however, only holds good when the p_H values of the extracts are greater than 4. The p_H values of soil extracts the hydrogen ion concentration of

which is in proximity of the neutral point is shifted about + 0.6 when the carbonic acid is removed. In case the hydrogen ion concentration of the soil extracts is greater, the p_H value is altered to a smaller degree when removing the carbonic acid. Soil extracts the p_H value of which is near 5 are thus altered about + 0.2. Thus it appears that the soil extracts must not stand for a longer time before the measurements are made, as otherwise carbonic acid will escape.

At a series of experiments with a few neutral or alkaline soils p_H was electrometrically determined partly after the soil, to which was added water, had been standing for 24 hours (the general procedure), partly after a current of atmospheric air had been passed through the mixture of soil and water for 24 hours and finally partly after a current of atmospheric air not containing carbonic acid had passed through the mixture of soil and water, also for 24 hours. The following p_H values were found as regards a very alkaline soil:

Treated in the ordinary way ..... $p_H = 8.0$
Atmospheric air being passed through ..... „ $= 8.2$
Atmospheric air not containing carbonic acid being passed through ..... „ $= 8.3$

If the soil deposition treated in the ordinary way was filtered, the p_H value 8.0 was also reached, as far as the filtered extract was concerned, but when a current of atmospheric air not containing carbonic acid was passed through the filtered extract for 24 hours, p_H was found to be = 9.0. It appears from these experiments that almost the same p_H values are reached by the procedure used by me, as those reached when the soil depositions are brought in equilibrium with the tension of the carbonic acid of the air, or when the carbonic acid is completely removed. As regards the filtered extract it makes an important difference — especially as regards the neutral and alkaline extracts — whether the carbonic acid is removed or not. It must be presumed that the solid particles of the soil depositions act like a buffer and work the comparatively small significance of the carbonic acid for the p_H value.

Extraction with different volumes of water. Experiments have been made to show the influence on the concentration of hydrogen ions of the soil extracts in case the relation between

soil and water was varied. The concentration of hydrogen ions of the extract appeared almost to be the same, whether the extract was the result of extracting 70 cc of soil with 70 cc of water or the double volume hereof.

The hydrogen ion concentration of the soil liquid as compared with that of the soil extract. As mentioned above I have at my researches determined the hydrogen ion concentration of an aquaeous extract. When extracting with water, the soil liquid is of course very much diluted and consequently it cannot be expected that the concentration of hydrogen ions measured in the extract is the same as that found in the soil liquid. Therefore, the hydrogen ion concentration measured in extracts cannot be considered as the real hydrogen ion concentration of the soils (the soil liquids), but only as a relative expression hereof. As, however, it might be of interest to know how much the concentration of hydrogen ions of the extract deviates from that of the natural soil liquid, a series of measurements was made to this effect, as it appeared that it was possible, when the soils were not too dry, by means of a hydraulic press to press a part of the soil liquid out of the soil. Apart from a single exception wood soils were used for these experiments, and it was necessary to take out samples of several kilos in order to have sufficient soil liquid for a measurement of the hydrogen ion concentration. The samples which were brought home in linen bags were severally well mixed; out of each of the great samples a smaller one — 70 cc — was taken out, the hydrogen ion concentration of which was then determined in an extract in the ordinary way. The main samples were then placed one at a time in the press cylinder, the holes of which were so small that the solid particles of the soil could not be pressed through[1]), and then the soil liquid was pressed out.

In the following table the p_H values, electrometrically measured, both of the extracts and of the soil liquid thus pressed out are indicated for a number of soils (the number of the localities

[1]) At the first experiments the soil was put into a linen bag and was then placed in the cylinder. As the results of the measurements of the hydrogen ion concentration, however, varied according to the bag being used or not, the bag was not used at the final experiment. It must be supposed that certain substances found in the soil liquid were adsorbed by the linen thus altering the hydrogen ion concentration.

refer to the corresponding numbers in the tables 18—26, 31 and 33, where the position of the localities as also their vegetation are stated).

Table 3.

Number of locality	p_H of the soil liquid	p_H of the extract	Difference (of the extract)
82	3.5	3.6	+ 0.1
88	3.7	3.8	+ 0.1
99	4.0	4.1	+ 0.1
276	4.4	4.8	+ 0.4
149	4.8	5.1	+ 0.3
178	5.1	5.6	+ 0.5
181	5.2	5.6	+ 0.4
219	6.2	6.5	+ 0.3
223	6.2	6.6	+ 0.4
298	7.7	7.7	0
258	7.8	7.6	− 0.2

It will be seen from the table that the difference between the p_H value of the soil liquid and that of the extract is not especially great as far as any of the soil samples goes; it is greatest for the soils the p_H value of which lies between 4.3 and 6.3, smallest for the very acid ones. The soil liquid is thus as regards acid soils more acid than the extract of the same soil, while the soil liquid in alkaline soils may be more alkaline than the extract. Plummer (1918) has reached similar results as regards arable soils.

The buffer action of the soil[1]). When the hydrogen ion concentration of the soil extract does not deviate more from that of the soil liquid than indicated above, it is of course due to the fact that the soil contains buffer. In order to examine the buffer action of the soil I have determined the hydrogen ion concentration produced in a mixture of soil and water to which gradually is added more acid or base. In fig. 2 the results will be seen of such an experiment made with a humified peaty soil, taken from Jaegersborg Deer-Park, and carrying a rich vegetation

[1]) A solution is said to contain buffer if an addition of small quantities of acid or base does not essentially alter its hydrogen ion concentration. See also S. P. L. Sørensen 1909, p. 17 and 48 f. f.

of *Urtica dioeca*. 100 g of the fresh soil were deposited in 200 cc of water; then the p_H value of the liquid was electrometrically determined after adding both increasing quantities of 1 n. sulphuric acid and increasing quantities of 1 n. sodium hydroxide. 1 cc was added at a time, and the measurement after each addition was not made until the following day, as the hydrogen ion concentration did not become constant at once. The titration curve reached through the experiment, which consequently expresses the ability of the soil to neutralize acid and base, shows that the soil is in possession of a rather considerable content of buffer. The characteristic flat portions[1]) of the curve over the p_H ranges 4.5—6.0 and 7.0—8.0 show that the effect of the buffer in these places is smaller.

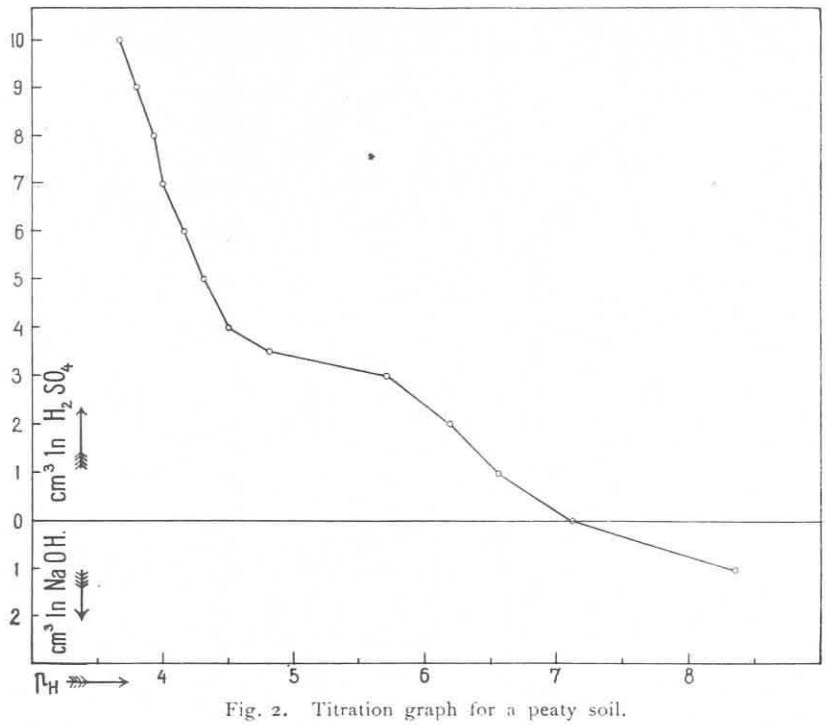


Fig. 2. Titration graph for a peaty soil.

[1]) As it might be supposed that the appearance of flat portions of the curve over the p_H range 4.5—6.0 might be due to experimental errors, the experiment was repeated with another soil sample. Quite the same result was reached. Also when using hydrochloric acid instead of sulphuric acid the result was the same.

Bjerrum and Gjaldbæk (1919 p. 63) have in a way similar to that indicated above made titration curves for two soils, i. e. garden soil and a subsoil of a wood bog.

While the soil thus is in possession of rather considerable buffer ability, the filtered soil extracts are quite otherwise. These extracts do not contain any buffer and therefore the addition of even small quantities of acids or bases can alter the concentration of hydrogen ions considerably. Consequently the greatest care must be exercised when measuring the concentration of hydrogen ions of soil extracts.

How homogeneous and constant is the hydrogen ion concentration of the soil? In a few localities I have examined the hydrogen ion concentration of the soil in different places within the same homogeneous habitat as regards vegetation (formation). The hydrogen ion concentration is of course not the same in all habitats, where the composition and physiognomy of the vegetation are the same. Within the same homogeneous habitat the different soil samples differed up to 0,5 in p_H from one another, but in most cases the deviations, however, were smaller. Furthermore it appeared that two soil samples taken from the same spot could deviate reciprocally 0.2 —0.3 in p_H. No essential difference appeared whether the soil samples were taken in a depth of 5, 10 or 20 cm., the reciprocal deviations were never greater than 0.3 in p_H.[1])

Finally samples have been taken out in a few localities with certain intervals during a period of 18 months, in order to examine whether the hydrogen ion concentration varies according to the season. The samples taken out at different times in the same locality might deviate up to 0.5 in p_H reciprocally, but it was not possible to observe any fixed influence of the season. The concentration of hydrogen ions of the very acid soils, e. g. the raw humus soils, is most constant; the greatest reciprocal deviation between the p_H values of the samples taken out on the same raw humus locality was 0.2.

The method used for examining the transformation processes of nitrogen in the soil. Soil samples of about one kilo

[1]) According to Arrhenius (1920) the concentration of hydrogen ions decreases for acid soils with increasing depth. Plummer (1918) on the other hand has observed as far as arable soil is concerned that the hydrogen ion concentration increases with increasing depth.

were taken out for examination. As the degree of moisture of the soil, as will be known, essentially influences the course of the nitrification (Koch 1911), the soil samples were only taken out in periods, in which the soil was neither very moist nor very dry, in order that the results might be compared with one another. 100 g were taken of each sample, which were afterwards dried to constant weight at about 18°. The difference between the two weighings is taken as an expression of the percentage content of water in the soil. The remaining parts of the samples were divided into two equal parts; in one half the volume of nitrate and ammonia was determined at once, the other half was transferred into a faïence jar and stood for a month in the Laboratory, covered with a glass sheet, and was then analized.

By means of the quantities of water found for the samples the amount of nitrate and ammonia found were passed into and expressed in mg. per one kilo dry soil. By comparing the quantities of nitrate and ammonia found in the samples at once and after one month it will be seen how much nitrogen is transferred during one month in a form accessible for the plants (ammonia, nitrate); thus it is possible to convey an idea of the course of the nitrification and the formation of ammonia in the soil.

The determination of nitrate. To determine the amount of nitrate I have used the phenoldisulphonic acid method, a colorimetric method which has been critically treated by Chamot and Pratt (1909, 1910), Stewart and Greaves (1910, 1913), Kelly (1913), Davis (1917), and Noyes (1919 II). The method depends on the following reaction: When the evaporation rest of a nitrate solution is treated with phenoldisulphonic acid, a lemon colour appears after neutralisation with a solution of strong potassium hydroxide; the intensity of this colour is determined by the quantity of nitrate when the phenoldisulphonic acid is found in excess. The yellow compound formed is the tripotassium salt of the nitrophenoldisulphonic acid (Chamot and Pratt 1910) and not, as often said, the potassium salt of the picric acid. The method has been critizised rather much, as some investigators (Kelly 1913, Chamot, Pratt and Redfield 1911) have ascertained loss of nitrate during the analysis. Davis (1917) has, however, shown that these losses are due to the fact that the said investigators have added solution of alum in order to facilitate the filtration of the soil extract, this solution as is well

known reacting like an acid on account of hydrolysis; during the subsequent evaporation of the soil extract nitric acid is lost; this, however, can very easily be prevented, when taking care that the extract reacts alkaline.

At the determination I have followed the following procedure, which has proved to give sufficient exact results: 100 g of fresh soil to which were added 200 cc of water and a small quantity of calciumsulphate (not containing nitrate) were left for an hour during which time it was frequently being stirred; then it was filtered. The addition of calcium sulphate causes that the filtrate quickly will become clear, and that it runs quickly through the filter. 100 cc of the filtrate was evaporated in a porcelain dish on waterbath after adding a small quantity of calciumoxide (about 0.25 g) to a volume of about 10 cc; then it was filtered through a little filter in another dish; the calciumoxide retained all the coloured substances of the extract, consequently the filtrate became completely colourless. The dish was rinsed over the funnel and the filter was washed completely with warm water. This colourless filtrate was evaporated until dryness on waterbath, and the evaporation rest was then treated with 2 cc of phenoldisulphonic acid which by aid of a glass spatula was brought in connection with the whole evaporation rest. After a quarter of an hour 25 cc of water were added and then 10 cc of 10 n potassium hydroxide solution; then the yellow colour appeared. The contents of the dish was then quantitatively transferred into a 200 cc volumetric flask which was made up with water to the mark; 100 cc of this solution were filtered that such precipitate, as generally appears, may be removed, after which the colour-tone of the solution was determined (by means of an ordinary colorimeter) in relation to that of a standard solution prepared in the same way and containing a known quantity of nitrate.

The phenoldisulphonic acid was prepared according to Chamot, Pratt and Redfield (1911) in the following way: 50 g of pure white phenol were disolved in 25 0cc of pure concentrated sulphuric acid, then 150 cc of fuming sulphuric acid was added (13 per cent SO_3) After being shaken the mixture was heated for two hours on boiling waterbath.

If the phenoldisulphonic acid method is used in the manner just described, it will give correct results within a limit of $\pm$ 4 pct. The determination of the color-tone of the yellow solution cannot

be done with greater exactitude than ± 4 per cent, this however being fully sufficient at the present investigations.

I have determined the reliability of the method and the size of the error by adding known quantities of nitrate partly to raw humus soils not containing nitrate, partly to nitrificating soils of which the nitrate has been washed out. I have then analized these soils and have recovered the added quantities of nitrate with the said exactitude[1]).

Another fact which I have examined closer is the influence exercised by the time of extraction on the result. A larger soil sample was carefully mixed, then smaller samples of 100 g each were taken out of the former. The quantity of nitrate was then determined in these smaller samples while the time of extraction was varied. It appeared that the above indicated time of extraction, i. e. one hour is sufficient, as more nitrate is never found when a longer time of extraction is used. When a time of extraction of 24 hours is used, as made by Weis and Bondorff (1917) and by the author of this work at former investigations (Olsen 1918), too low quantities of nitrate will be found, especially when the soils analized are alkaline. The reason hereof is without doubt the activity of the denitrification bacteria.

The determination of ammonia. As is well known, ammonia is highly adsorbed by the soil and consequently only a part of the ammonia found in the soil is found in an aqueous extract of a soil sample. If on the other hand extraction is made with salt solutions, the total quantity of ammonia will be found in the extract (Valmari 1912). The soil samples were, therefore, extracted with 0.5 n sodium chloride solution in the following way: 100 g of soil were shaken for an hour in a shaking machine with 200 cc of 0.5 n sodium chloride solution, after

[1]) If on the other hand baryta water and not calcium oxide, as mentioned above, was used to remove the coloured substances dissolved in the soil extract, results will be reached which might be subject to very great errors — up to ± 40 per cent; this method has been used by Weis and Bondorff (1917) and by the author of the present work at former investigations (Olsen 1918). This is due to two reasons: firstly a very violent reaction appears when adding phenoldisulphonic acid in case baryta water has been used; hereby nitrogen oxide, which might directly be observed as reddish brown damps, may disappear. Secondly a very great quantity of barium sulphate is formed when adding phenoldisulphonic acid, which incloses a greater or smaller part of the nitrophenoldisulphonic acid.

which the extract was filtered. A certain portion of the filtrate (10—100 cc according to the amount of ammonia found in the extract, as the portion used for the determination must not contain more than 0.8 mg NH_4) was diluted with water till 300 cc and was then distilled with 2 g of magnesia in a Kjeldahl-distilling apparatus; the distillate being gathered in a long-necked 200 cc volumetric flask, containing 5 cc of $^n/_7$ hydrochloric acid. The distillation was continued until the distillate filled the flask till the mark. The amount of ammonia was then colorimetrically determined according to Nessler by adding 5 cc of $^n/_5$ sodium hydroxide solution and 2 cc potassic mercuric iodide solution. This was made in the manner indicated by Classen (1903 p. 115).

As liquids of comparison in the colorimetric Nessler-determination solution containing known quantities of ammonia sulphate were used, to which were added 5 cc of $^n/_7$ hydrochloric acid and was made up with water to 200 cc, then 5 cc of $^n/_5$ sodium hydroxide solution and 2 cc potassic mercuric iodide solution were added.

The determination of the colour-tone of the Nessler-analysis in relation to that of the liquids of comparison was made the day after the preparation of the samples by aid of an ordinary colorimeter.

It is a matter of course that water not containing ammonia was used at the preparation of the sodium chloride solution, as also the water used for dilution, filling e. t. c. did not contain ammonia.

At a number of investigations the same soil was extracted both with 0.5 n sodium chloride solution and with distilled water. When analizing the extracts it appeared that when extracting with water only a quarter of the quantity of ammonia is obtained of that obtained when using 0.5 n sodium chloride solution.

As to the literature on the determination of ammonia in soils, I refer to Baumann (1887), Valmari (1912) and Richmond (1918).

The determination of the contents of the soil of easily soluble mineral plant nutrients. The soil of some of the localities examined were extracted with distilled water saturated with carbonic acid, and in this extract the quantity of potassium, phosphate and calcium was determined. Owing to the circum-

stantiality of these analysis it is a very restricted number of localities, the soil of which has been analized to determine the said substances; thus no analysis have been made of the soil taken from the meadow localities examined.

The three said plant nutrients have been determined by aid of the method described by Mitscherlich (1907, 1917) one kilo fresh soil being extracted with 5 litres of distilled water. Extraction was made for 12 hours, while the mixture was being frequently stirred which was made mechanically by a glass stirring apparatus worked by an electromotor and by constantly passing carbonic acid through the mixture. The extract thus obtained was filtered according to Mitscherlich through a Chamberland filter.

At the determination of calcium the procedure described by Mitscherlich was closely followed. Furthermore the quantity of potassium was determined according to the method indicated by Mitscherlich and his assistants (Mitscherlich, Celichowski and Fischer 1911, Mitscherlich and Fischer 1912; see also Zaleski 1913 and H. Fischer 1914); hereby potassium is precipitated as sodium-potassium cobalti-nitrite, the quantities hereof were determined by titration with potassium permanganate. The analysis were made in close conformity with the procedure indicated by Mitscherlich. The quantity of phosphate was, on the other hand, not determined according to Mitscherlich, but according to the alkalimetric method described by Neumann and Gregersen (Gregersen 1907). I have previously described this procedure (Olsen 1918, p. 38).

The quantity of calcium, potassium and phosphate extracted is in the following given in mg per one kilo dry soil.

The hydrogen ion concentration of the meadow soil and the distribution of meadow plants.

As the object was to study the distribution of the meadow plants in relation to a single factor, i. e. the hydrogen ion concentration of the soil, it was expedient that the habitats of the formations examined differed as little as possible as regards other factors. The formations examined therefore are all found on peaty soil, just as they all are found in open places, as such places have been avoided where the shade might be supposed

to affect the vegetation. Many of the meadows examined are, it is true, surrounded by wood, but as these meadows all are very extensive, I have been able to select localities so far from the wood that it was out of the question that the shade might have any effect whatever. None of the localities examined are nearer to the outskirts of the wood than 30 m. Furthermore all the meadows examined are such as are regularly cut. I have avoided meadows that after hay-making are used for cattle-grazing as the cattle-traffic, as far as I have been able to observe, causes a partial alteration of the composition of the vegetation. Finally it is a matter of course that meadows to which have been added manures, or which have been subject to ploughings, sowing or similar cultural intrenchements have been avoided.

The degree of moisture might essentially influence the vegetation and its composition. Therefore it was the original object only to examine meadows, the soils of which were all in the same height over the surface of the subsoil water. This, however, very soon appeared impracticable, as partly the number of meadows suitable for the investigations in consequence hereof would become extremely limited, partly as the researches had to be made at almost the same time, as the level of the subsoil water in the meadows varies very much in the course of the year. Finally it does not quite follow that two meadows the level of the subsoil water of which at a given time lies in the same depth under the surface, also at another time will be lying in the same depth. Therefore it was soon given up only to examine meadows the subsoil water of which was in a certain depth below the surface.

At the final researches localities were included in which the level of the subsoil water at the time of the investigations, i. e. from the beginning of July to the end of September 1920, was found to lie from 30—100 cm below the surface of the meadow. The meadows, which thus were not included in the examinations, were partly the most moist ones, the vegetation of which essentially consists in cyperacees, partly the very dry ones. The level of the subsoil water was observed in ditches and peat pits, of which some always were found in the neighbourhood. I want moreover to observe that the level of the subsoil water in the localities examined hardly have undergone great fluctuations in the period during which the examinations were made.

76 localities have in all been examined of which most are from meadows in the north of Seeland, a few from middle Seeland and from Buderup valley near Skørping in Jutland. Besides the position of the single localities as also the results of the investigations will appear from the tables 4—12; in these tables the formations examined are arranged according to the hydrogen ion concentration of the soil on the habitats in such a way that the formations from the habitats in the soil of which the lowest p_H values are found, are taken first. Each table comprises formations from soils the p_H values of which are within a range of 0.5 in p_H. Thus 9 tables result, as the p_H values found at the analysis of all the soil samples may be grouped in 9 p_H classes, each comprising a range of 0.5. Each vertical column in the

Table 4. Analysis of meadow habitats and their vegetation.

p_H 3.5—3.9.

Locality nos. 1, 2 and 3 are situated in Bure Sea (Grib Forest), no. 4 in Grøftemose (Grib Forest), nos. 5 and 6 in a meadow at the eastern border of Maglemose (Grib Forest) and no. 7 in a meadow in Rold Forest.

p_H of the soil sample	3.8	3.8	3.8	3.8	3.8	3.8	3.9
Number of locality	1	2	3	4	5	6	7
Carex Goodenoughii	50	»	10	»	»	»	»
Molinia coerulea	100	100	100	100	100	60	100
Deschampsia flexuosa	100	80	90	100	100	60	70
Sieglingia decumbens	»	»	»	»	»	60	10
Agrostis tenuis	»	»	»	10	»	50	»
Anthoxanthum odoratum	10	»	»	»	»	80	10
Nardus stricta	»	»	»	»	»	60	»
Potentilla erecta	60	50	70	60	90	60	80
Galium harcynicum	100	100	100	60	100	100	100
Rumex acetosa	30	40	10	»	20	30	10
Viola palustris	»	20	10	»	10	»	10
Peucedanum palustre	»	»	»	»	10	10	»
Calluna vulgaris	»	»	10	40	10	»	20
Vaccinium vitis idaea	»	»	»	30	»	»	10
Number of species	7	6	8	7	8	10	10
Density of species	4.5	3.9	4.0	4.0	4.4	5.7	4.2
Level of subsoil water in cm	30	50	40	50	40	60	100

Table 5. Analysis of meadow habitats and their vegetation.

p_H 4.0—4.4.

Locality no. 8 is situated in Glarborg Dam (Grib Forest), no. 9 in Rørmose (the northern part of Grib Forest), no. 10 in Sortemose at Farum Sea, nos. 11 and 13 in a meadow in Allindelille Fredskov, nos. 12 and 14 in a meadow south of the halting-place "Slotspavillonen" at the Grib Forest railway.

p_H of the soil sample	4.0	4.1	4.2	4.3	4.4	4.4	4.4
Number of locality	8	9	10	11	12	13	14
Eriophorum vaginatum	30	30	50	»	»	»	»
Carex Goodenoughii	»	»	60	»	»	80	»
— panicea	80	»	»	30	»	30	10
Festuca ovina	100	»	»	»	»	»	»
Molinia coerulea	50	100	40	100	100	100	100
Holcus lanatus	»	»	»	»	80	»	20
Deschampsia flexuosa	»	80	100	»	50	»	40
Agrostis canina	»	»	»	100	»	100	»
— tenuis	»	»	»	»	90	»	»
Anthoxanthum odoratum	90	»	10	»	»	»	40
Viola palustris	10	100	»	60	»	50	»
Potentilla erecta	90	100	100	100	100	100	100
Hydrocotyle vulgaris	90	»	»	»	»	»	»
Calluna vulgaris	»	30	10	100	»	»	»
Oxycoccus quadripetalus	»	100	100	10	»	»	»
Galium harcynicum	90	100	»	»	»	»	40
Luzula multiflora	10	»	»	»	»	»	»
Eriophorum polystachyum	»	»	40	»	»	»	»
Carex rostrata	10	»	»	»	»	»	»
— sp.	»	»	»	»	10	»	»
Festuca rubra	»	»	»	»	30	40	40
Salix repens	»	»	30	»	10	»	»
Rumex acetosa	40	10	»	»	40	»	30
Anemone nemorosa	»	»	»	30	»	40	»
Potentilla palustris	»	»	20	»	»	»	10
Peucedanum palustre	»	»	»	30	»	»	10
Achillea ptarmica	»	»	»	»	10	»	10
Hypochoeris radicata	»	40	»	»	40	»	»
Number of species	12	10	11	9	11	8	12
Density of species	6.9	6.9	5.6	5.6	5.6	5.4	4.5
Level of subsoil water in cm	40	40	30	40	50	30	50

Table 6. Analysis of meadow habitats and their vegetation.

p_H 4.5—4.9.

Locality no. 15 is situated in a meadow in Strøgaardsvang (Grib Forest), nos. 16, 18, 20 and 21 in Store Ondemose (Grib Forest), no. 17 in Bure Sea (Grib Forest) and no. 19 in Sortemose at Farum Sea.

p_H of the soil sample.....	4.5	4.6	4.6	4.7	4.7	4.8	4.9
Number of locality.....	15	16	17	18	19	20	21
Carex stellulata.....	»	»	»	»	50	»	»
— Goodenoughii.....	»	»	100	»		»	»
— panicea.....	10	»	»	»	100	»	»
Festuca ovina.....	»	»	»	90	40	10	»
— rubra.....	70	20	»	»	»	40	»
Molinia coerulea.....	10	20	10	100	100	50	30
Deschampsia flexuosa.....	»	»	»	50	30	»	»
Sieglingia decumbens.....	»	»	»	»	60	10	»
Agrostis canina.....	»	»	»	»	100	»	»
— tenuis.....	»	»	»	100	»	80	100
Anthoxanthum odoratum....	100	100	100	30	20	100	100
Salix repens.....	»	»	»	10	60	20	»
Rumex acetosa.....	30	40	80	»	»	»	20
Viola palustris.....	»	»	10	»	80	50	50
Potentilla erecta.....	50	100	50	30	100	60	50
— palustris.....	»	20	10	»	50	10	»
Geum rivale.....	60	»	»	»	»	»	»
Hydrocotyle vulgaris.....	»	»	100	»	80	»	»
Peucedanum palustre.....	»	»	»	»	60	30	»
Veronica officinalis.....	»	»	»	60	»	»	»
Plantago lanceolata.....	60	»	»	30	»	»	»
Campanula rotundifolia.....	»	60	»	40	»	»	20
Galium harcynicum.....	40	»	20	80	»	20	40
Hieracium pilosella.....	»	80	»	20	»	»	»
Carex sp.....	»	»	»	»	10	»	»
Holcus lanatus.....	20	20	30	30	10	20	»
Rumex acetosella.....	20	»	»	10	»	»	»
Ranunculus acer.....	20	10	»	»	»	10	»
Hypericum perforatum.....	»	»	»	10	»	»	»
Calluna vulgaris.....	»	10	10	»	»	10	10
Menyanthes trifoliata.....	»	»	»	»	10	»	»
Succisa pratensis.....	»	»	»	»	10	»	»
Hypochoeris radicata.....	»	»	»	10	»	»	10
Number of species.....	12	11	11	16	18	15	10
Density of species.....	4.9	4.8	5.2	7.0	9.7	5.2	4.3
Level of subsoil water in cm	50	80	40	35	30	70	70

Table 7. Analysis of meadow habitats and their vegetation.

p_H 5.0—5.4.

Locality nos. 22, 24 and 26 are situated in Sortemose at Farum Sea, no. 23 in Buderup valley at Skørping, no. 25 in a meadow south of the halting-place "Slotspavillonen" at the Grib Forest railway, no. 27 in the large meadow in Stenholt enclosure (Grib Forest), no. 28 in Store Ondemose in Strøgaardsvang (Grib Forest) and no. 29 in a meadow, north-east of Selbæk Mose (Grib Forest).

p_H of the soil sample	5.0	5.0	5.1	5.1	5.3	5.3	5.3	5.4
Number of locality	22	23	24	25	26	27	28	29
Luzula multiflora	20	30	60	»	»	60	»	»
Carex stellulata	50	»	»	»	»	»	»	»
— Goodenoughii	10	100	»	»	»	»	»	»
— panicea	80	10	30	10	»	10	»	10
— lasiocarpa	»	»	»	»	100	»	»	»
Festuca rubra	80	30	50	100	80	100	100	30
Poa pratensis	40	»	»	80	»	70	»	»
Holcus lanatus	40	»	80	100	70	80	90	»
Sieglingia decumbens	50	40	»	»	»	»	»	»
Calamagrostis lanceolata	»	»	»	»	60	»	»	»
Agrostis canina	»	70	100	20	100	»	»	»
— tenuis	100	»	»	40	»	40	100	»
Anthoxanthum odoratum	100	90	100	30	20	100	100	100
Salix repens	»	»	»	20	20	»	90	»
Rumex acetosa	»	»	20	50	»	50	10	30
Ranunculus acer	»	»	»	30	»	40	»	90
Viola palustris	100	100	80	10	40	»	»	»
Potentilla erecta	100	100	100	20	100	40	80	40
— palustris	10	40	70	10	100	30	»	30
Geum rivale	»	»	60	»	»	50	»	100
Hydrocotyle vulgaris	70	»	20	»	70	»	»	»
Veronica officinalis	»	»	»	»	»	»	100	»
Nepeta glechoma	»	»	»	»	»	100	»	»
Campanula rotundifolia	»	»	»	»	»	»	100	»
Galium palustre	»	»	10	»	»	100	»	20
Cirsium palustre	»	»	40	»	30	50	»	10
Achillea millefolium	»	»	»	100	»	»	60	»
Eriophorum vaginatum	»	10	»	»	10	»	»	»
Carex rostrata	»	40	»	»	10	»	»	»
— sp.	»	»	»	10	»	»	»	»
Festuca ovina	30	»	40	»	»	»	»	»
Molinia coerulea	»	»	»	10	20	»	10	»
Deschampsia caespitosa	»	»	»	40	»	»	»	»
Avena pubescens	10	»	»	10	»	30	10	»
Cerastium caespitosum	»	»	»	»	»	»	20	»
Lychnis flos cuculi	»	»	10	»	»	»	»	»
Filipendula ulmaria	»	»	»	»	»	10	»	»
Epilobium palustre	»	»	»	»	»	»	»	10
Peucedanum palustre	10	»	»	»	»	»	»	»
Calluna vulgaris	»	30	»	»	»	»	10	»
Oxycoccus quadripetalus	40	»	10	»	30	»	»	»
Veronica chamaedrys	»	»	»	20	»	»	»	»
Plantago lanceolata	»	»	»	30	»	»	40	30
Brunella vulgaris	»	»	»	»	10	»	»	»
Menyanthes trifoliata	»	40	»	»	»	»	»	»
Galium harcynicum	»	»	»	»	»	»	20	»
Valeriana sp.	»	»	»	»	10	»	»	»
Succisa pratensis	10	»	»	»	»	»	10	»
Achillea ptarmica	10	»	»	»	»	»	10	»
Hieracium pilosella	40	»	»	10	»	»	10	»
Taraxacum sp.	»	»	»	20	»	40	»	»
Number of species	21	14	17	22	18	18	19	12
Density of species	10.0	7.3	8.8	7.7	8.8	10.0	9.7	5.0
Level of subsoil water in cm	35	40	30	40	30	100	70	40

Table 8. Analysis of meadow habitats and their vegetation.

PH· 5·5—5·9.

Locality nos. 30 and 36 are situated in Sortemose at Farum Sea, no. 31 in a meadow in Strøgaardsvang (Grib Forest), nos. 32 and 33 in Selbæk Mose in Tibberup Holme (Grib Forest), no. 34 in Tokkerup Enghave (Grib Forest), nos. 35, 37 and 43 in Store Ondemose in Strøgaardsvang (Grib Forest), no. 38 in Bure Sea (Grib Forest), no. 39 in Buderup valley at Skørping, nos. 40 and 42 in the large meadow in Stenholt enclosure (Grib Forest) and no. 41 in Lille Hæssemose (northern part of Grib Forest).

pH· of the soil sample	5·5	5·5	5·5	5·5	5·5	5·6	5·6	5·6	5·6	5·7	5·7	5·7	5·8	5·9
Number of locality	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Carex pulicaris	»	»	»	»	»	»	»	»	»	60	»	»	»	»
— Goodenoughii	70	»	»	»	»	»	100	»	»	100	»	»	»	»
— panicea	10	40	»	»	»	»	60	»	»	100	»	»	»	»
Dactylis glomerata	»	»	»	»	»	10	»	70	»	»	»	»	»	»
Festuca rubra	100	100	100	100	90	100	100	100	100	100	100	100	100	100
Poa pratensis	»	60	60	»	60	10	»	40	»	»	60	40	100	100
Holcus lanatus	100	70	50	80	20	70	70	100	30	60	100	»	40	100
Deschampsia caespitosa	100	10	»	30	100	100	»	20	100	»	»	10	100	100
Sieglingia decumbens	»	»	»	»	»	»	»	»	»	70	»	»	»	»
Calamagrostis lanceolata	»	»	»	80	»	»	»	»	»	»	»	»	»	»
Agrostis canina	70	»	10	»	»	»	100	»	»	70	»	»	»	»
— tenuis	»	»	40	»	50	20	»	40	90	»	»	»	»	»
Anthoxantum odoratum	100	100	100	100	»	40	100	60	60	100	100	100	40	»
Rumex acetosa	40	50	90	20	20	10	»	10	100	»	100	50	10	80
Ranunculus acer	100	100	80	70	30	10	100	40	100	20	80	»	10	»
Viola palustris	»	»	»	»	»	10	60	70	»	100	»	»	»	»
Potentilla erecta	50	»	»	»	»	20	80	»	»	40	»	»	»	»
— palustris	60	»	»	»	»	»	50	»	»	80	80	»	»	»
Geum rivale	60	70	100	90	30	30	»	100	»	»	100	100	100	»
Veronica chamaedrys	40	»	»	30	»	»	»	»	10	»	»	»	»	50
Plantago lanceolata	20	100	60	20	»	»	»	100	»	»	»	90	»	50
Brunella vulgaris	»	»	»	»	»	»	40	10	»	60	»	»	»	»
Menyanthes trifoliata	»	»	»	»	»	»	»	»	»	50	»	»	»	»
Campanula rotundifolia	»	»	10	»	»	20	»	»	»	»	»	»	»	80
Galium palustre	»	10	20	20	50	»	10	»	40	40	100	»	»	»
Taraxacum sp.	»	»	»	»	»	60	»	100	»	»	»	»	»	»
Hypochoeris radicata	»	»	»	»	»	»	»	80	»	»	»	»	»	»
Juncus effesus	»	»	»	»	»	»	»	»	10	»	»	»	»	»
— sp.	»	»	»	»	»	»	»	»	»	10	»	»	»	»
Luzula multiflora	»	»	»	40	»	»	30	»	»	10	40	»	»	»
Eriophorum polystachyum	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Carex rostrata	»	»	»	»	»	»	»	»	»	10	»	»	»	»
— sp.	»	»	»	»	»	»	10	10	»	»	10	»	»	»
Festuca ovina	10	»	»	»	»	20	30	»	»	»	»	»	»	»
— elatior	»	40	»	»	»	»	10	»	»	»	»	»	»	»
Briza media	»	»	»	»	»	»	10	»	»	40	»	»	»	»
Phragmites communis	»	»	»	»	»	»	»	»	»	»	»	10	»	»
Avena pratensis	»	»	»	»	»	»	»	»	»	»	»	»	»	10
— pubescens	»	40	»	»	»	»	»	»	»	»	»	»	10	»
Salix repens	»	»	»	»	»	»	»	»	»	10	»	»	»	»
Cerastium caespitosum	»	»	»	»	»	»	»	»	»	»	10	»	»	»
Stellaria Dilleniana	»	»	»	»	»	»	»	»	»	»	40	»	»	»
Filipendula ulmaria	»	»	10	10	»	»	»	»	»	»	»	»	»	»
Vicia cracca	»	»	»	»	»	»	30	»	»	»	»	»	»	»
Lathyrus pratensis	»	40	»	»	»	»	»	»	»	»	40	»	»	»
Trifolium pratense	»	»	»	»	»	»	»	40	»	40	»	»	»	»
Lotus corniculatus	»	»	»	»	»	»	»	»	»	30	»	»	»	»
Hydrocotyle vulgaris	40	»	»	»	»	»	40	»	»	»	»	»	»	»
Oxycoccus quadripetalus	20	»	»	»	»	»	40	»	»	10	»	»	»	»
Veronica officinalis	»	»	»	»	»	10	»	»	»	»	»	»	»	»
Scutellaria galericulata	40	»	»	»	»	»	»	»	»	»	»	»	»	»
Nepeta glechoma	»	»	»	»	»	»	»	»	»	»	30	»	»	»
Menta aquatica	10	»	»	»	»	»	»	»	»	»	»	»	»	»
Galium harcynicum	»	»	»	»	»	»	»	»	10	»	»	20	»	»
Succisa pratensis	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Cirsium palustre	10	»	»	40	»	40	20	30	»	»	»	»	»	»
Hieracium pilosella	»	»	»	»	»	30	»	10	»	40	»	»	»	»
Number of species	20	14	13	14	9	18	23	19	11	24	15	9	9	9
Density of species	10.5	8.3	7.3	7.3	4.5	6.1	11.1	10.3	6.5	12.5	9.9	5.2	5.1	6.7
Level of subsoil water in cm	30	50	100	70	70	70	30	50	50	40	100	100	100	70

Table 9. Analysis of meadow habitats and their vegetation. p_H 6.0—6.4.

Locality nos. 44 and 53 are situated in Rørmose between Roskilde and Boserup wood, nos. 45 and 51 part of Grib Forest), no. 48 in Lerbæks Rende in Store Bøgeskov at Gyrstinge, nos. 49 and 50 in the large meadow in Stenholt enclosure (Grib Forest), nos. 47 and 52 in Lille Hæssemose (northern Buderup valley at Skørping, nos. 46 and 54 in a meadow in Strøgaardsvang (Grib Forest).

p_H of the soil sample	6.0	6.0	6.0	6.0	6.2	6.2	6.2	6.2	6.2	6.3	6.3
Number of locality	44	45	46	47	48	49	50	51	52	53	54
Carex paradoxa	»	»	»	»	»	»	»	»	»	50	
— Goodenoughii	»	10	80	»	»	70	100	»	»	»	»
— panicea	»	»	»	»	»	70	10	»	»	90	»
Dactylis glomerata	70	»	»	»	»	»	»	»			
Festuca rubra	60	100	100	100	100	100	60	100	100	30	100
— elatior	70	»	»	»	»	»	»	»	»	»	»
Poa pratensis	80	50	»	80	20	»	40	50	100	»	100
Briza media	»	»	»	»	»	70	30	»	»	»	»
Phragmites communis	»	»	»	»	»	40	»	»	»	50	
Molinia coerulea	»	»	»	»	»	»	»	»	»	50	»
Holcus lanatus	60	50	100	»	10	60	70	60	»	»	40
Deschampsia caespitosa	90	20	80	50	70	»	»	20	100	30	100
Avena pubescens	10	»	»	»	»	»	»	50	»	»	»
Agrostis canina	»	»	100	»	»	»	»	»	»	»	»
Cynosurus cristatus	»	»	»	»	»	50	»	»	»	»	»
Anthoxanthum odoratum	»	70	80	100	70	100	100	50	40	»	»
Rumex acetosa	70	20	80	90	»	50	40	100	50	»	40
Ranunculus acer	70	50	90	»	40	50	100	40	40	30	70
Cardamine pratensis	»	60	»	»	»	20	»	»	»	»	»
Parnassia palustris	»	»	»	»	»	»	30	»	»	60	»
Filipendula ulmaria	30	»	»	40	60	»	20	»	»	10	80
Potentilla erecta	»	»	»	»	»	40	»	»	»	50	»
— reptans	»	»	»	»	»	»	70	»	»	»	»
— anserina	»	»	»	»	»	»	60	»	»	»	»
— palustris	»	30	»	10	»	»	»	50	»	»	»
Geum rivale	90	»	»	70	100	100	100	50	100	»	100
Lotus corniculatus	»	»	»	»	»	70	100	»	»	»	»
Hydrocotyle vulgaris	»	»	70	»	»	»	»	»	»	»	»
Veronica chamaedrys	»	»	»	»	20	»	»	»	»	»	60
Plantago lanceolata	»	»	70	»	»	100	100	»	30	»	100
Brunella vulgaris	»	»	20	»	10	90	»	»	»	70	»
Menta aquatica	»	»	»	»	»	»	»	»	»	50	»
Galium palustre	10	10	»	30	100	70	100	50	»	10	50
Succisa pratensis	»	»	»	»	»	»	»	»	»	50	»
Cirsium palustre	»	»	»	»	40	20	70	»	»	40	»

p_H of the soil sample	6.0	6.0	6.0	6.0	6.2	6.2	6.2	6.2	6.2	6.3	6.3
Number of locality	44	45	46	47	48	49	50	51	52	53	54
Equisetum arvense	»	»	»	»	20	»	»	»	»	»	»
Luzula multiflora	»	»	»	»	»	»	40	»	»	»	»
Carex pulicaris	»	»	»	»	»	»	»	»	»	20	»
— glauca	»	»	»	»	10	»	»	»	»	30	»
— rostrata	»	»	»	»	»	»	20	»	»	»	»
— sp.	»	»	»	»	»	»	»	»	»	20	»
Festuca ovina	30	»	»	»	»	10	»	»	»	»	»
Avena pratensis	»	»	»	»	»	»	»	»	»	»	10
Salix repens	»	»	»	»	»	»	»	»	»	20	»
Lychnis flos-cuculi	»	»	10	»	»	»	10	»	»	»	»
Ranunculus flammula	»	»	10	»	»	»	»	»	»	»	»
— repens	»	»	»	»	20	»	»	»	»	»	»
Viola palustris	»	»	»	»	10	40	10	»	»	»	»
Lathyrus pratensis	30	»	»	»	40	»	»	40	»	»	»
Trifolium pratense	»	»	»	»	»	30	»	»	»	»	»
Angelica silvestris	»	»	»	»	»	»	30	»	»	40	»
Veronica scutellata var. villosa	»	»	»	»	20	»	»	»	»	»	»
Euphrasia curta	»	»	»	»	»	10	»	»	»	»	»
Alectorolophus major	»	»	»	»	»	»	10	»	»	»	»
Pinguicula vulgaris	»	»	»	»	»	10	»	»	»	»	»
Plantago lanceolata var.dubia	»	»	»	»	»	»	»	»	»	»	10
Ajuga reptans	»	»	»	»	10	»	»	»	»	»	»
Galium uliginosum	»	»	»	»	»	»	»	40	»	»	»
— boreale	»	»	»	»	»	»	»	»	»	40	»
Valeriana dioeca	»	»	»	»	10	»	»	»	»	»	»
Tussilago farfarus	»	»	»	»	»	»	10	»	»	»	»
Achillea millefolium	»	»	»	»	»	»	10	»	»	»	»
Hieracium pilosella	»	»	»	»	10	30	»	»	»	»	»
Crepis praemorsa	»	»	»	»	»	»	»	»	»	10	»
Taraxacum sp.	»	»	»	»	»	»	»	»	»	20	»
Number of species	14	11	13	9	21	24	26	13	8	23	13
Density of species	7.7	4.7	8.9	5.7	7.9	13.0	13.4	7.0	5.6	8.7	8.6
Level of subsoil water in cm	60	100	30	70	100	40	40	100	70	50	100

Table 10. Analysis of meadow habitats and their vegetation.

p_H 6.5—6.9.

Locality no. 55 is situated in Lyngby Mose, no. 56 in Rørmose between Roskilde and Bosrup wood, no. 57 in Grønnekilde meadow (Grib Forest), nos. 58 and 61 in the large meadow in Stenholt enclosure, nos. 59 and 62 i Selbæk Mose in Tibberup Holme (Grib Forest) and no. 60 in Sortemose at Farum Sea.

p_H of the soil sample	6.5	6.5	6.6	6.7	6.7	6.8	6.8	6.8
Number of locality	55	56	57	58	59	60	61	62
Scirpus silvaticus	60	»	»	30	»	20	100	40
Carex rostrata	30	»	100	»	»	»	»	»
Dactylis glomerata	50	100	»	20	»	»	»	60
Festuca ovina	»	50	»	»	»	»	»	»
— rubra	100	70	100	»	100	100	100	100
— elatior	20	40	»	90	100	100	60	20
Poa pratensis	50	30	»	»	60	30	80	30
Briza media	»	»	»	20	»	70	»	»
Holcus lanatus	100	40	100	70	20	100	100	60
Deschampsia caespitosa	»	40	»	10	»	»	70	10
Avena elatior	»	»	»	»	40	»	»	60
Alopecurus pratensis	»	»	»	»	100	»	»	60
Rumex acetosa	20	30	100	20	100	20	»	20
Trollius europaeus	»	10	»	»	»	»	80	»
Ranunculus acer	20	60	100	10	50	70	40	60
Linum catharticum	»	»	»	»	60	»	»	»
Filipendula ulmaria	80	30	30	70	40	50	50	50
Geum rivale	100	100	100	30	40	20	»	100
Lathyrus pratensis	»	»	»	»	»	70	40	»
Angelica silvestris	50	20	»	»	20	»	»	40
Veronica chamaedrys	»	»	»	10	10	60	10	40
Plantago lanceolata	»	30	100	»	20	40	30	100
Valeriana dioeca	60	»	»	»	»	»	»	»
Cirsium oleraceum	80	30	»	100	»	80	100	100
Equisetum palustre	»	»	»	»	»	»	10	»
Juncus lampocarpus	»	»	»	»	»	10	»	»
Carex elata	»	»	»	»	»	10	»	»
— Goodenoughii	»	»	10	»	»	»	»	»
— glauca	»	»	»	»	»	40	»	»
— panicea	»	»	20	»	»	10	»	»
— acutiformis	40	»	»	»	»	»	»	»
— hirta	»	»	»	20	»	»	10	»
Carex sp.	»	»	10	»	»	»	»	30
Phragmites communis	»	»	40	»	»	30	»	»
Molinia coerulea	»	40	»	»	»	»	»	»
Avena pratensis	»	»	»	»	20	»	»	»
— pubescens	»	10	»	40	»	»	40	»
Trisetum flavescens	»	»	»	»	10	»	»	40
Agrostis alba	»	»	»	»	»	30	»	»
Anthoxanthum odoratum	»	20	40	»	20	»	»	»
Polygonum amphibium	»	»	»	»	»	10	»	»
Parnassia palustris	10	»	»	»	»	»	»	»
Potentilla erecta	»	10	»	»	»	»	»	»
— palustris	»	»	20	»	»	»	»	»
Vicia cracca	»	»	»	»	»	10	»	»
Trifolium pratense	»	»	»	»	»	40	»	»
Epilobium palustre	40	»	40	»	»	»	»	»
Carum carvi	»	20	»	»	»	»	»	»
Anthriscus silvester	»	20	»	»	»	»	»	10
Primula veris	»	10	»	»	»	»	»	»
Brunella vulgaris	40	40	»	»	»	40	»	»
Nepeta glechoma	»	»	»	20	»	»	»	10
Menta aquatica	»	40	»	»	»	»	40	»
Galium palustre	»	20	10	»	40	40	»	»
Succisa pratensis	»	20	»	»	»	30	»	»
Cirsium palustre	20	»	40	10	»	40	»	10
Tussilago farfarus	»	»	»	»	10	»	»	»
Achillea ptarmica	»	20	»	»	»	»	10	»
— millefolium	»	»	»	»	»	10	»	»
Taraxacum sp.	»	10	»	»	»	»	10	»
Number of species	19	28	17	16	19	28	19	22
Density of species	9.7	9.6	9.6	5.7	8.6	11.8	9.8	10.5
Level of subsoil water in cm	40	50	30	100	100	30	100	100

Table 11. Analysis of meadow habitats and their vegetation.

p_H 7.0—7.4.

Locality no. 63 is situated in Buderup valley at Skorping, nos. 64, 65, 66 and 67 in Rormose in a meadow south of Konge between Roskilde and Boserup wood, nos. 68 and 70 in Sortemose at Farum Sea and no. 69 port at Jægersborg deer-park.

p_H of the soil sample	7.0	7.0	7.0	7.1	7.3	7.3	7.3	7.4
Number of locality	63	64	65	66	67	68	69	70
Scirpus silvaticus	»	»	»	»	»	»	»	100
Carex paradoxa	»	»	»	50	»	»	»	»
— Goodenoughii	100	»	»	40	»	»	»	»
— glauca	30	100	»	60	20	50	»	»
— panicea	»	»	»	80	»	40	»	»
Dactylis glomerata	»	20	»	»	100	»	100	100
Festuca rubra	70	100	80	90	80	100	»	80
— elatior	»	100	100	»	100	100	20	100
Poa pratensis	»	»	»	»	20	60	60	70
Briza media	10	»	»	40	»	70	»	70
Phragmites communis	20	40	20	60	»	»	10	20
Molinia coerulea	»	»	»	50	»	»	»	10
Holcus lanatus	100	30	60	»	70	»	50	80
Deschampsia caespitosa	»	40	»	100	20	50	»	50
Avena pubescens	»	»	»	»	»	70	»	80
— elatior	»	»	»	»	»	»	100	»
Agrostis alba	»	»	80	»	50	»	»	»
Rumex acetosa	100	»	20	»	30	»	»	»
Ranunculus acer	100	90	70	»	90	100	»	90
Linum catharticum	»	»	»	»	»	»	»	70
Parnassia palustris	»	50	»	»	»	»	»	»
Filipendula ulmaria	»	10	»	50	»	»	»	»
Potentilla anserina	»	»	70	»	»	»	»	»
Geum rivale	100	50	»	10	30	90	»	40
Vicia cracca	»	50	»	»	»	»	»	»
Lathyrus pratensis	100	100	»	20	»	»	»	»
Trifolium pratense	100	10	»	»	»	»	»	»
Angelica silvestris	»	50	80	»	»	20	»	40
Convolvulus sepium	»	»	»	»	»	»	100	»
Euphrasia tenuis	50	»	»	»	»	»	»	»
Plantago lanceolata	100	50	10	»	»	80	»	10
Brunella vulgaris	80	20	»	100	»	70	»	»
Menta aquatica	»	»	40	»	30	»	»	100
Galium palustre	»	10	»	»	»	40	»	60
Succisa pratensis	10	80	»	10	»	60	»	10
Cirsium oleraceum	»	100	100	60	100	100	100	100
— palustre	50	»	»	30	»	»	10	»
Tussilago farfarus	40	»	50	»	80	»	50	»
Taraxacum sp.	»	»	60	»	20	»	»	40
Equisetum fluviatile	10	30	10	»	»	»	»	»
Juncus lampocarpus	10	30	»	»	10	»	»	»
Triglochin maritima	20	»	»	»	»	»	»	»
Carex hirta	10	»	»	»	»	»	»	20
Anthoxanthum odoratum	»	»	»	»	»	30	»	»
Orchis latifolius	»	»	»	»	»	»	»	10
Helleborine palustris	»	»	»	10	»	»	»	»
Cerastium caespitosum	10	»	»	»	10	»	»	»
Trollius europaeus	»	30	30	»	»	»	»	20
Hypericum maculatum	»	»	»	20	»	»	»	»
Potentilla erecta	»	10	»	40	»	»	»	10
— reptans	»	»	»	20	»	»	»	»
Trifolium repens	20	»	»	»	»	»	»	»
Lotus corniculatus	20	»	»	»	»	»	»	»
Anthriscus silvester	»	»	»	»	20	»	»	»
Peucedanum palustre	»	»	»	»	10	»	»	»
Lysimachia vulgaris	»	»	»	10	»	»	»	»
Veronica chamaedrys	»	»	»	»	»	10	»	»
Plantago major	30	»	10	»	»	30	»	»
Nepeta glechoma	»	»	10	»	»	»	»	»
Galium uliginosum	»	20	»	»	»	»	»	»
Centaurea jacea	10	»	»	»	»	»	»	»
Eupatorium cannabinum	»	»	»	»	»	»	»	10
Achillea ptarmica	»	»	»	»	»	10	»	»
— millefolium	10	20	»	»	»	»	»	»
Inula salicina	»	»	»	»	20	»	»	»
Crepis praemorsa	»	»	»	10	»	»	»	»
Number of species	27	26	18	22	20	20	10	26
Density of species	13.1	12.4	9.0	9.6	9.1	11.8	6.0	13.9
Level of subsoil water in cm.	40	50	60	40	70	50	60	30

Table 12. Analysis of meadow habitats and their vegetation.

Locality no. 71 is situated in Rørmose between Roskilde and Boserup wood, no. 72 in Sorte Mose at Farum Sea, nos. 73, 74 and 75 in a meadow south of Kongeport at Jægersborg deer-park and no. 76 in a meadow south of Rødeport at Jægersborg deer-park.

p_H of the soil sample	7.5	7.5	7.5	7.5	7.6	7.7
Number of locality	71	72	73	74	75	76
Scirpus silvaticus	»	60	»	»	»	100
Carex Goodenoughii	»	60	»	»	»	»
— glauca	50	60	»	»	»	»
— acutiformis	»	»	»	»	»	70
— hirta	»	30	80	20	»	10
Dactylis glomerata	80	»	70	60	40	»
Festuca rubra	100	100	100	»	100	100
— elatior	100	100	40	»	»	50
Poa pratensis	10	50	30	10	»	30
Briza media	»	100	»	»	»	»
Phragmites communis	50	10	»	60	»	10
Holcus lanatus	30	10	100	30	10	70
Avena pubescens	»	100	»	»	»	»
— elatior	»	»	50	30	»	»
Agrostis alba	20	»	20	100	100	»
Phleum pratense	50	»	»	»	»	10
Ranunculus acer	80	100	10	»	»	»
Linum catharticum	»	100	»	»	»	»
Potentilla reptans	10	»	»	70	»	»
— anserina	50	»	»	70	»	50
Lathyrus pratensis	»	»	»	»	»	50
Nepeta glechoma	»	»	»	60	»	30
Menta aquatica	10	20	10	100	»	»
Cirsium oleraceum	100	100	100	90	80	70
Tussilago farfarus	»	»	90	80	»	70
Taraxacum sp.	100	»	10	»	»	»
Equisetum palustre	40	40	20	»	»	»
Luzula multiflora	»	10	»	»	»	»
Carex panicea	»	40	»	»	»	»
Glyceria aquatica	»	»	»	10	»	»
Deschampsia caespitosa	20	40	»	»	10	20
Avena pratensis	»	»	10	»	»	»
Anthoxanthum odoratum	»	30	»	»	»	»
Rumex hydrolapathum	»	»	»	»	10	»
Polygonum amphibium	»	»	»	»	10	»
Trollius europaeus	40	»	»	»	»	»
Hypericum acutum	»	»	»	»	»	10
Geum rivale	10	40	»	»	»	»
Alchemilla alpestris	»	»	»	20	»	»
Vicia cracca	»	10	»	»	»	»
Trifolium procumbens	»	10	»	»	»	»
— pratense	»	20	»	»	20	»
Medicago lupulina	»	40	»	»	»	»
Lythrum salicaria	»	»	»	»	10	»
Anthriscus silvester	»	»	»	»	20	»
Angelica silvestris	40	»	30	30	»	20
Convolvulus sepium	»	»	»	30	20	»
Veronica chamaedrys	»	10	»	»	»	»
Pedicularis palustris	»	10	»	»	»	»
Plantago lanceolata	20	40	»	»	»	»
Galium palustre	»	»	»	»	»	10
Cirsium arvense	»	»	»	»	»	20
Number of species	21	28	16	17	12	19
Density of species	10.1	13.4	7.7	8.7	4.3	8.0
Level of subsoil water in cm	50	30	70	40	50	70

Table 13. Analysis of meadow habitats and their vegetation.

The localities are situated in Sortemose at the western side of Farum Sea where grass moor with alkaline peaty soil (locality nos. 72 and 70) over a distance of a few hundred metres passes gradually into high moor (locality nos. 77 and 78). The table shows the increasing hydrogen ion concentration of the peat in the direction of the high moor and the consequent alterations of the vegetation. The number of the localities refer to tables 4—12, in which the analysis mentioned here also are stated, apart from localities nos. 77 and 78 (high moor localities). The level in the subsoil water was in all the localities 30 cm.

p_H of the soil sample	7.5	7.4	6.8	5.6	5.5	5.3	5.1	4.7	4.2	3.8	3.6
Number of locality	72	70	60	36	30	26	24	19	10	77	78
Scirpus silvaticus	60	100	20	»	»	»	»	»	»	»	»
Carex Goodenoughii	60	»	»	100	70	»	»	»	60	40	»
— glauca	60	»	40	»	»	»	»	»	»	»	»
Festuca rubra	100	80	100	100	100	80	50	»	»	»	»
— elatior	100	100	100	10	»	»	»	»	»	»	»
Poa pratensis	50	70	30	»	»	»	»	»	»	»	»
Briza media	100	70	70	10	»	»	»	»	»	»	»
Avena pubescens	100	80	»	»	»	»	»	»	»	»	»
Ranunculus acer	100	90	70	100	100	»	»	»	»	»	»
Linum catharticum	100	70	»	»	»	»	»	»	»	»	»
Cirsium oleraceum	100	100	80	»	»	»	»	»	»	»	»
Dactylis glomerata	»	100	»	»	»	»	»	»	»	»	»
Holcus lanatus	10	80	100	70	100	70	80	10	»	»	»
Deschampsia caespitosa	40	50	»	»	100	»	»	»	»	»	»
Menta aquatica	20	100	»	»	10	»	»	»	»	»	»
Galium palustre	»	60	40	10	»	»	10	»	»	»	»
Filipendula ulmaria	»	»	50	»	»	»	»	»	»	»	»
Lathyrus pratensis	»	»	70	»	»	»	»	»	»	»	»
Veronica chamaedrys	10	»	60	»	40	»	»	»	»	»	»
Carex panicea	40	»	10	60	10	»	30	100	»	»	»
Agrostis canina	»	»	»	100	70	100	100	100	»	»	»
Anthoxanthum odoratum	30	»	»	100	100	20	100	20	10	»	»
Viola palustris	»	»	»	60	60	40	80	80	»	»	»
Potentilla erecta	»	10	»	80	50	100	100	100	100	»	»
— palustris	»	»	»	50	»	100	70	50	20	»	»
Geum rivale	40	40	20	»	60	»	60	»	»	»	»
Carex lasiocarpa	»	»	»	»	»	100	»	»	»	»	»
Calamagrostis lanceolata	»	»	»	»	»	60	»	»	»	»	»
Hydrocotyle vulgaris	»	»	»	40	40	70	20	80	»	»	»
Luzula multiflora	10	»	»	30	»	»	60	»	»	»	»
Carex stellulata	»	»	»	»	»	»	»	50	»	»	»
Molinia coerulea	»	10	»	»	»	20	»	100	40	10	»
Sieglingia decumbens	»	»	»	»	»	»	»	60	»	»	»
Salix repens	»	»	»	»	»	20	»	60	30	»	»
Peucedanum palustre	»	»	»	»	»	»	»	60	»	»	»
Eriophorum vaginatum	»	»	»	»	»	10	»	»	50	100	100
Deschampsia flexuosa	»	»	»	»	»	»	»	30	100	»	»
Oxycoccus quadripetalus	»	»	»	40	20	30	10	»	100	100	100
Drosera rotundifolia	»	»	»	»	»	»	»	»	»	40	50
Calluna vulgaris	»	»	»	»	»	»	»	»	10	40	80
Andromeda polifolia	»	»	»	»	»	»	»	»	»	10	50
Equisetum palustre	40	»	»	»	»	»	»	»	»	»	»
Juncus lampocarpus	»	»	10	»	»	»	»	»	»	»	»
Eriophorum polystachyum	»	»	»	10	»	»	»	»	40	»	»
Carex elata	»	»	10	»	»	»	»	»	»	»	»
— rostrata	»	»	»	»	»	10	»	»	»	»	»
— hirta	30	20	»	»	»	»	»	10	»	»	»
— sp.	»	»	»	10	»	»	»	»	»	»	»
Festuca ovina	»	»	»	30	10	»	40	40	»	»	»
Phragmites communis	10	20	30	»	»	»	»	»	»	»	»
Agrostis alba	»	»	30	»	»	»	»	»	»	»	»
Orchis latifolius	»	10	»	»	»	»	»	»	»	»	»
Rumex acetosa	»	»	20	»	40	»	20	»	»	»	»
Polygonum amphibium	»	»	10	»	»	»	»	»	»	»	»
Lychnis flos-cuculi	»	»	»	»	»	»	10	»	»	»	»
Trollius europaeus	»	20	»	»	»	»	»	»	»	»	»
Vicia cracca	10	»	10	30	»	»	»	»	»	»	»
Trifolium procumbens	10	»	»	»	»	»	»	»	»	»	»
— pratense	20	»	40	»	»	»	»	»	»	»	»
Medicago lupulina	40	»	»	»	»	»	»	»	»	»	»
Angelica silvestris	»	40	»	»	»	»	»	»	»	»	10
Erica tetralix	»	»	»	»	»	»	»	»	»	»	»
Pedicularis palustris	10	»	»	»	»	»	»	»	»	»	»
Plantago lanceolata	40	10	40	»	20	»	»	»	»	»	»
Brunella vulgaris	»	»	40	40	»	10	»	»	»	»	»
Scutellaria galericulata	»	»	»	»	40	»	»	»	»	»	»
Menyanthes trifoliata	»	»	»	»	»	»	»	10	»	»	»
Valeriana sp.	»	»	»	»	»	10	»	»	»	»	»
Succisa pratensis	»	10	30	10	»	»	»	10	»	»	»
Cirsium palustre	»	»	40	20	10	30	40	»	»	»	»
Eupatorium cannabinum	»	10	»	»	»	»	»	»	»	»	»
Achillea millefolium	»	»	10	»	»	»	»	»	»	»	»
Taraxacum sp.	»	40	»	»	»	»	»	»	»	»	»
Number of species	28	26	28	23	20	18	17	18	11	7	7
Density of species	13.4	13.9	11.8	11.1	10.5	8.8	8.8	9.7	5.6	3.4	3.9

Table 14. The average frequency of the meadow plants in the p_H classes.

p_H classes	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	Occurence on number of localities
Deschampsia flexuosa	86	68	40	»	»	»	»	»	»	13
Galium harcynicum	94	77	40	20	15	»	»	»	»	18
Molinia coerulea	94	84	46	13	»	50	40	30	»	28
Potentilla erecta	67	99	63	73	48	45	10	20	»	39
Calluna vulgaris	20	47	10	20	»	»	»	»	»	13
Viola palustris	13	55	48	66	60	20	»	»	»	24
Agrostis tenuis	30	90	93	70	48	»	»	»	»	15
Oxycoccus quadripetalus	»	70	»	27	23	»	»	»	»	9
Hydrocotyle vulgaris	»	90	90	53	40	70	»	»	»	9
Agrostis canina	»	100	100	73	63	100	»	»	»	12
Festuca ovina	»	100	47	35	20	20	50	»	»	12
Anthoxanthum odoratum	33	47	79	80	83	76	27	30	30	46
Carex Goodenoughii	30	70	100	55	90	65	10	70	60	18
Holcus lanatus	»	50	22	77	68	56	74	65	42	55
Hieracium pilosella	»	»	50	20	27	20	»	»	»	10
Rumex acetosa	23	30	43	32	48	60	44	50	»	50
Carex panicea	»	38	55	25	53	57	15	60	40	24
Festuca rubra	»	37	43	71	99	86	96	86	100	58
Geum rivale	»	»	60	70	78	89	70	53	25	37
Plantago lanceolata	»	»	45	33	63	80	53	50	30	30
Salix repens	»	20	30	43	10	20	»	»	»	10
Luzula multiflora	»	10	»	43	30	40	»	»	10	11
Potentilla palustris	»	15	23	41	68	30	20	»	»	21
Galium palustre	»	»	»	43	36	48	28	37	10	28
Poa pratensis	»	»	»	63	59	65	47	53	26	35
Ranunculus acer	»	»	13	53	62	58	51	90	63	45
Veronica chamaedrys	»	»	»	20	33	40	26	10	10	14
Deschampsia caespitosa	»	»	»	40	67	62	33	52	23	33
Taraxacum sp.	»	»	»	30	80	20	10	40	55	12
Succisa pratensis	»	»	10	10	10	50	25	34	»	12
Cirsium palustre	»	»	»	33	28	43	24	30	»	21
Phragmites communis	»	»	»	»	10	45	35	28	33	15
Brunella vulgaris	»	»	»	10	37	48	40	68	»	15
Menta aquatica	»	»	»	»	10	50	40	57	35	11
Dactylis glomerata	»	»	»	»	40	70	58	80	63	15
Festuca elatior	»	»	»	»	25	70	61	87	73	20
Briza media	»	»	»	»	25	50	45	48	100	11
Filipendula ulmaria	»	»	»	10	10	40	50	30	»	19
Lathyrus pratensis	»	»	»	»	40	37	55	73	50	11
Cirsium oleraceum	»	»	»	»	»	»	82	94	90	19
Scirpus silvaticus	»	»	»	»	»	»	50	100	80	8
Trifolium pratense	»	»	»	»	40	30	40	55	20	8
Avena pubescens	»	»	»	15	25	30	30	75	100	14
Angelica silvestris	»	»	»	»	»	35	33	48	30	14
Carex glauca	»	»	»	»	»	20	40	52	55	10
Tussilago farfarus	»	»	»	»	»	10	10	55	80	9
Agrostis alba	»	»	»	»	»	»	30	65	60	7
Carex hirta	»	»	»	»	»	»	15	15	35	8
Average number of species	8.0	10.4	13.3	17.6	14.8	15.9	21.0	21.1	18.8	
Average density of species	4.4	5.8	5.9	8.4	8.0	8.3	9.4	10.6	8.7	

Table 15. Meadow plants. Number of occurrences in the p_H classes (per cent).

p_H classes	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	Number of occurrences
Deschampsia flexuosa	**54**	31	16	»	»	»	»	»	»	13
Galium harcynicum	**41**	18	29	5	6	»	»	»	»	18
Molinia coerulea	**26**	**26**	**26**	10	»	2	3	7	»	28
Potentilla erecta	**20**	**20**	**20**	**20**	6	4	3	8	»	39
Calluna vulgaris	**31**	24	**31**	14	»	»	»	»	»	13
Viola palustris	20	20	20	**22**	10	9	»	»	»	24
Agrostis tenuis	17	8	25	**29**	21	»	»	»	»	15
Oxycoccus quadripetatus	»	**42**	37	21	»	»	»	»	»	9
Hydrocotyle vulgaris	»	13	28	**37**	13	9	»	»	»	9
Agrostis canina	»	22	11	**38**	22	7	»	»	»	12
Festuca ovina	»	10	**32**	19	16	13	10	»	»	12
Anthoxanthum odoratum	8	8	**20**	**20**	17	14	7	3	3	46
Carex Goodenoughii	14	14	7	12	10	**17**	6	12	8	18
Holcus lanatus	»	5	14	12	**15**	12	**15**	12	**15**	55
Hieracium pilosella	»	»	27	**36**	20	17	»	»	»	10
Rumex acetosa	15	10	10	11	15	15	**16**	7	»	50
Carex panicea	»	20	10	**26**	10	10	9	9	6	24
Festuca rubra	»	7	7	**15**	**15**	**15**	14	14	13	58
Geum rivale	»	»	4	10	18	19	**22**	19	8	37
Plantago lanceolata	»	»	9	11	15	14	**23**	19	10	30
Salix repens	»	23	**34**	30	6	7	»	»	»	10
Luzula multiflora	»	12	»	**42**	24	8	»	»	17	11
Potentilla palustris	»	12	23	**36**	12	11	5	»	»	21
Galium palustre	»	»	»	13	20	**29**	18	13	6	28
Poa pratensis	»	»	»	10	17	19	20	13	**22**	35
Ranunculus acer	»	»	9	8	18	19	**21**	16	10	45
Veronica chamaedrys	»	»	»	9	19	12	**41**	9	11	14
Deschampsia caespitosa	»	»	»	4	21	**24**	14	18	19	33
Taraxacum sp.	»	»	»	17	10	0	17	**26**	23	12
Succisa pratensis	»	»	10	17	5	6	17	**44**	»	12
Cirsium palustre	»	»	»	22	16	16	**28**	17	»	21
Phragmites communis	»	»	»	»	4	9	13	**39**	35	15
Brunella vulgaris	»	»	»	8	13	23	24	**32**	»	15
Menta aquatica	»	»	»	»	5	6	17	26	**46**	11
Dactylis glomerata	»	»	»	»	7	5	26	26	**35**	15
Festuca elatior	»	»	»	»	6	4	**35**	30	20	20
Briza media	»	»	»	»	11	15	20	**40**	14	11
Filipendula ulmaria	»	»	»	6	7	27	**48**	12	»	19
Lathyrus pratensis	»	»	»	»	12	22	21	**31**	14	11
Cirsium oleraceum	»	»	»	»	»	»	29	33	**38**	19
Scirpus silvaticus	»	»	»	»	»	»	**58**	12	30	8
Trifolium pratense	»	»	»	»	15	10	14	27	**35**	8
Avena pubescens	»	»	»	**31**	9	11	23	15	10	14
Angelica silvestris	»	»	»	»	»	10	27	27	**36**	14
Carex glauca	»	»	»	»	»	14	10	**50**	26	10
Tussilago farfarus	»	»	»	»	»	7	11	**41**	**41**	9
Agrostis alba	»	»	»	»	»	»	12	24	**64**	7
Carex hirta	»	»	»	»	»	»	21	21	**57**	8

Table 16. Meadow plants. Number of occurrences with frequency 50 and upwards in the p_H classes (per cent).

p_H classes	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9	Number of occurrences
Deschampsia flexuosa	44	33	22	»	»	»	»	»	»	11
Galium harcynicum	54	36	11	»	»	»	»	»	»	10
Molinia coerulea	26	23	11	»	»	26	»	13	»	18
Potentilla erecta	22	22	19	14	11	11	»	»	»	28
Viola palustris	»	26	26	21	26	»	»	»	»	12
Agrostis tenuis	15	29	29	15	12	»	»	»	»	9
Agrostis canina	»	22	22	17	17	22	»	»	»	10
Anthoxanthum odoratum	9	9	18	19	22	23	»	»	»	30
Holcus lanatus	»	11	»	17	16	16	16	17	7	35
Rumex acetosa	»	»	10	16	21	27	12	14	»	18
Festuca rubra	»	»	5	12	17	15	17	17	17	50
Geum rivale	»	»	21	21	16	21	12	10	»	27
Plantago lanceolata	»	»	17	»	24	27	11	20	»	15
Potentilla palustris	»	»	13	16	54	18	»	»	»	8
Galium palustre	»	»	»	22	17	38	»	22	»	9
Poa pratensis	»	»	»	19	19	21	14	21	6	21
Ranunculus acer	»	»	»	9	15	16	17	26	18	27
Deschampsia caespitosa	»	»	»	»	28	32	12	28	»	16
Dactylis glomerata	»	»	»	»	13	27	20	20	20	11
Festuca elatior	»	»	»	»	»	32	18	26	24	13
Filipendula ulmaria	»	»	»	»	»	23	43	34	»	8
Cirsium oleraceum	»	»	»	»	»	»	30	35	35	18

tables contains the analytical results of a single locality, for which is stated the p_H value[1]) found in the aqueous extract of the soil sample, the depth of the level of the subsoil water below the surface of the meadow (the level of the subsoil water) at the time at which the investigation took place and the species[2])

[1]) The p_H values given in the tables are those colorimetrically measured; besides all the extracts of the soil samples are also electrometrically measured, but the p_H values electrometrically found are not stated in the table.

[2]) At the formation statistical investigations only the vascular plants were noted. These are in the present work designated by the names found in Raunkjær's Danish excursion flora (1914).

found by the formation-statistical analysis in the selected trial areas, as also their frequency. At the bottom of the columns the number of species found in all the selected trial areas together with the density of the species (the average number of species on the trial area) are stated.

A single one of the localities examined, i. e. "Sortemose" at the western side of Farum Sea, will be more fully entered upon. The southern part of the Sortemose is a high moor partly covered with firs and birch-trees; the northern part on the other hand is a grass moor, on which *Cirsium oleraceum* is the dominant plant, and the soil of which is alkaline (p_H 7.1—7.5). From this grass moor the hydrogen ion concentration of the peat increases over a distance of a few hundred metres evenly towards the high moor, the peaty soil of which is extremely acid (p_H 3.6). Parallel to the alteration of the hydrogen ion concentration of the soil is an alteration of the composition of the vegetation. From the alkaline grass moor I wandered in the direction of the high moor, and with certain intervals an area of 2 m^2 was selected for investigation. The result hereof will be seen from the table 13, in which the analytical results are stated[1]). It appears that the concentration of hydrogen ions of the peat increases towards the high moor and at the same time the features of the vegetation change. In the alkaline, the neutral and the slightly acid meadow (p_H 7.5—6.8) *Cirsium oleraceum* is the physiognomically dominant species; besides *Briza media* and *Festuca elatior* form an essential part of the vegetation; nearer to the high moor, where the concentration of hydrogen ions of the peat is higher (p_H 5.6—4.7) these species disappear and *Anthoxanthum odoratum*. *Agrostis canina*, *Viola palustris* and *Potentilla erecta* form an essential part of the vegetation. Near the high moor where the hydrogen ion concentration of the peat has a value of 4.7 in p_H, *Molinia coerulea* appears and becomes the dominant species. Where the hydrogen ion concentration of the peat expressed in p_H has a value of 4.2 or lower values, the high moor vegetation dominates in which *Eriophorum vaginatum*,

[1]) In table 13 the formations are contrary to the formations in the other tables arranged according to decreasing p_H values. This has been made because the alkaline grass moor in Sortemose in respect of development is the primary one, the high moor the secondary one, the latter having developped on the top of the grass moor. The table thus shows a succession.

Oxycoccus quadripetalus, *Calluna* and *Andromeda* figure prominantly. It will be seen from table 13 that both the number of the species as also their density decrease with the increasing hydrogen ion concentration of the peat. Moreover it will be seen that the level of the subsoil water in all localities is the same; consequently the moisture conditions cannot be of any importance to the plant distribution. The analytical results stated in table 13 — the two high moor formations always excepted — besides also form part of the principal tables (tables 4—12), containing the result of all analysis of formations and habitats made on the meadow soil.

In order to obtain a summary of the distribution of the single species in relation to the hydrogen ion concentration of the soil on the basis of all the material examined by me, I have statistically treated the aggregate material of the tables 4—12. As mentioned above, the results of the analysis of the localities have been classed in 9 groups according to the p_H values found at the analysis of the meadow habitats, each group comprising a p_H range of 0.5. Based on the number of frequency in tables 4—12, I have for each single species computed its average frequency[1]) in each of the p_H classes in which it is found. The result will be seen from table 14, in which of course only such

[1]) When computing the average frequency of the species in the different p_H classes, regard has only been taken to the localities in which the species occur. The fact that a plant does not occur in a given locality, does not say anything of the ability of the species to thrive in this locality or not, as accidental circumstances may have involved that the plant has not got any opportunity whatever to grow here. If one desires to compute the average frequency of a given species by adding up the numbers of frequency for each single p_H class and divide with the total number of localities examined in the p_H class in question, an uncorrect image of the distribution of the species would in many cases be obtained. A plant as *Hordeum europaeum* (the average frequency of which in the different p_H classes will be found in table 27 on the wood ground plants) thus is very frequent in the middle of Seeland, but is wanting in the north of Seeland. As the greater part of the wood habitats mentioned in the following and examined by me are taken from the north of Seeland, it will be seen that if regard is paid to the total number of the localities examined when computing the average frequency, figures would be come at which entirely would depend on the number of localities examined in the north of Seeland, where the species is not found. If furthermore a great number of localities is examined in the north of Seeland, and if these localities preferably fall on single p_H classes it will easily be understood that the average thus come at will be quite other than that first reached and by no means proportional to those first come at.

species are mentioned which are found in so many of the localities that a statistical treatment of the numbers of frequency is possible. Each figure in table 14 thus is an average number of all the numbers of frequency for a single species in a single p_H-class. Besides it is a matter of course that the table also states in which p_H-classes the species mentioned in the table are found. By means of the figures a graph may be drafted for each single species; the apex of the graph is in the p_H-class in which the species has its greatest frequency. An even graph is not always obtainable for all species. In some cases the graph may have an irregular course, which i. a. is due to the fact that not all the figures are averages of a sufficient number of frequency. If this was the case (several Hundred of localities should then have been examined) regular graphs would certainly have appeared. However, it must be noted that several of the irregular graphs, e. g. the graphs for *Festuca ovina* and *Taraxacum sp.*, have two apeces. This may perhaps follow from the fact that it is a question of two polymorpheous species, the two apeces severally may form the apex of a single graph representing a single race of the species. In the table is stated for each species in how many out of the 76 localities examined it occurs. Moreover by aid of the tables 4—12 it will easily be seen on how many figures each of the averages in table 14 is based.

As will be seen from table 14, the single species are arranged in such a way that the species having the greatest frequency on the most acid soils are set first, while the species most frequently found on alkaline soil are set at the bottom. The species mentioned first in the table are the "lime-avoiding" plants of the elder authors (e. g. *Deschampsia flexuosa* and *Calluna vulgaris*), those at the bottom their "lime-loving" plants (e. g. *Tussilago farfarus*).

In table 14 will moreover be found for each single p_H-class the average of the number of species found in the localities examined as also the average of their density. It will be seen that both the number of the species as their density on an average is greater on habitats with neutral-slightly alkaline soil (p_H 7.0—7.4), and that both the number of the species and their density decrease with increasing hydrogen ion concentration of the soil; on the very alkaline soils (p_H 7.5—8.0) both the number of the species as their density are on an average lower

than on the neutral-slightly alkaline soils. By means of the averages for both the number of the species as the density hereof a graph may be drawn, the apex of which is near the neutral point.

Furthermore I have examined as regards the single species how the number per cent. of occurences — without regard to the frequency — is distributed on the 9 p_H classes. The result will be seen from table 15. By aid of the figures in this table a graph may also be drawn for each species, the apex of which is in the p_H class in which the species is most often found. Moreover, when comparing this table with table 14[1]), it will be seen that the single species as a rule occur most frequently in the same p_H classes in which they have their greatest average frequency.

In table 16 will finally be found for the single species a summary of how the per cent. number of occurrences with 50 or more as number of frequency is distributed on the 9 p_H classes[2]).

It will appear from table 14, 15 and 16 that the single species only are found on soil the hydrogen ion concentration of which lies within certain limits, i. e. within a certain range of p_H, and that this range differs as regards the different species. Some species are seen to appear within a more limited range than others. The species the p_H of which is narrowly limited may, therefore, when very frequently found serve as a kind of indicator of the hydrogen ion concentration of the soil. Thus *Cirsium oleaceum*, *Angelica silvestris*, *Agrostis alba* and *Tussilago farfarus* will indicate that the hydrogen ion concentration of the soil expressed in p_H lies between 6.5 and 8.0, *Deschampsia caespitosa*, especially where large tussocks are formed, indicates the hydrogen ion concentration to be 5.5 and 6.5 and finally *Molinia coerulea* and *Deschampsia flexuosa* indicate that the hydrogen ion concentration is between 3.8 and 4.5. On the other hand no single species is found which might especially serve as indicator of the p_H range 4.5—5.5.

[1]) The species in table 15 are arranged in the samme succession as in table 14.

[2]) When computing the figures in table 15 and 16 (as also in the following table 28) regard has been paid to the fact that equal numbers of localities have not been examined in each p_H class, which has not been made in the Danish edition. Thus the figures of these three tables do not agree with those in the Danish edition.

Determination of the hydrogen ion concentration of the meadow soil through the vegetation. A more minute determination of the hydrogen ion concentration of the meadow soil through the vegetation can, however, be made when using for this purpose not a single species, but a greater number of species found, and when regard is taken to the frequency with which they are found. In this case it will be necessary on the spot to make a formation-statistical analysis. For such an analysis, however, it is sufficient to select 5 trial areas. At these determinations I have made use of a method which will appear from the following 3 instances.

The first instance is an analysis of a formation taken from a meadow south of Jægersborg deer-park. 5 trial areas were altogether selected. The species found and their frequency were then noted in the two first columns of a table as the following one; in this table will besides be found 9 columns corresponding to the above mentioned 9 p_H· classes. As regards *Festuca rubra*, the first stated species, the frequency of which is 100, table 14 was then examined to see in which p_H· classes this species has an average frequency[1]) near 100, and as this was found to be the case for the last 5 p_H· classes, a level line was drawn through the last 5 columns off the species. Then I continued with the other species in the same manner, provided that the species was found in table 14, and if so only provided a fairly regular "graph" was found, which e. g. is not the case as regards *Taraxacum*. Then the number of the lines for each p_H· class was added up, and the hydrogen ion concentration of the meadow soil expressed in p_H· should then be in the p_H· class for which the highest number of lines was found, in this case in the p_H· class 7.5—7.9. A soil sample taken on the locality in question also gave a colorimetrically measured p_H· value of 7.6.

The second instance of such a determination made on a meadow locality in Strøgaards Vang (Grib Forest) is shown in the following table (instance 2). Also in this case only 5 trial areas were selected at the formation-statistical examination. As

[1]) It is a matter of course that in many cases it depends on a judgement whether an average number of frequency entered in table 14 for a given species is to be considered as being near the figure found for the species in the formation examined or not. Fixed rules may of course be given here, but for the present I have not deemed it necessary.

Instance 1. Meadow locality south of Jægersborg deer-park.

Species	No. of frequency	p_H classes								
		3.5—3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	6.5—6.9	7.0—7.4	7.5—7.9
Festuca rubra	100	. . .	. . .	. . .	. . .	———	———	———	———	———
Festuca elatior	100	. . .	. . .	. . .	. . .	. . .	———	———	———	———
Briza media	100	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	———
Avena pubescens	100	. . .	. . .	. . .	. . .	. . .	. . .	. . .	———	———
Ranunculus acer	100	. . .	. . .	. . .	. . .	. . .	. . .	. . .	———	———
Linum catharticum	100							•		
Cirsium oleraceum	100	. . .	. . .	. . .	. . .	. . .	. . .	———	———	———
Taraxacum sp.	100									
Scirpus silvaticus	80	. . .	. . .	. . .	. . .	. . .	. . .	. . .	———	———
Carex glauca	80	. . .	. . .	. . .	. . .	. . .	. . .	. . .	———	———
Phragmites communis	60	. . .	. . .	. . .	. . .	. . .	———			
Phleum pratense	60									
Potentilla anserina	40									
Geum rivale	40	. . .	. . .	———	. . .	. . .	. . .	. . .	———	———
Plantago lanceolata	40	. . .	. . .	———	———	. . .	. . .	———	———	———
Avena pratensis	20									
Menta aquatica	20	. . .	. . .	. . .	. . .	———				
Hypericum acutum	20									
				2	1	2	3	4	9	10

Instance 2. Meadow locality in Strøgaards Vang (Grib Forest).

Species	No. of frequency	p_H classes								
		3.5—3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	6.5—6.9	7.0—7.4	7.5—7.9
Festuca rubra	100	.	.	.	.	—	—	—	—	—
Holcus lanatus	100	.	.	.	—	—	—	—	—	
Anthoxanthum odoratum	100	.	.	—	—	—	—			
Geum rivale	100	.	.	.	—	—	—	—		
Plantago lanceolata	100	.	.	.	.	—	—			
Rumex acetosa	60	.	.	.	.	—	—	—	—	
Galium palustre	40	.	.	.	—	—	—	—	—	
Poa pratensis	20	.	.	.	.	.	.	.	.	—
Lathyrus pratensis	20	.	.	.	.	—	—			
Taraxacum sp.	20									
				1	4	**8**	**8**	5	4	2

Instance 3. Locality Nr. 14 (see table 5).

Species	No. of frequency	p_H classes								
		3.5—3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	6.5—6.9	7.0—7.4	7.5—7.9
Molinia coerulea	100	—	—							
Potentilla erecta	100	.	—							
Deschampsia flexuosa	40	.	.	—				•		
Anthoxanthum odoratum	40	—	—	.	.	.	.	—	—	—
Oxycoccus quadripetalus	40									
Festuca rubra	40	.	—	—						
Rumex acetosa	30	.	—	—	—					
Holcus lanatus	20									
Carex panicea	10									
Potentilla palustris	10	.	—							
Peucedanum palustre	10									
Achillea ptarmica	10									
		2	6	3	1			1	1	1

will appear from the table the result was that the hydrogen ion concentration of the meadow soil expressed in p_H probably was near 6, the p_H class 5.5—5.9 being as probable as that 6.0—6.4. A soil sample taken on the spot had the p_H value 5.8.

Finally the third instance (page 62) is stated. For this determination one of the localities included in the preceding tables, i. e. locality no. 14 (see table 5) was used in the soil of which the hydrogen ion concentration expressed in p_H was found to be 4.4.

By means of the said procedure I have "determined" the soil on a number of meadow localities in the north of Seeland, these localities as those in instance 1 and 2 are not included in the material, on which table 14 is based, and controlled the result by aid of the soil samples selected. Furthermore, I have tried the procedure on the majority of the formations mentioned in tables 4—12, the hydrogen ion concentration of their habitats being known beforehand. On the basis of these examinations it can be said that through the said procedure the hydrogen ion concentration in most cases can be determined in the "right" p_H class. There are, however, cases were the right p_H class is not found, i. e. the p_H class in which lies the p_H value of the soil sample measured, but a p_H class immediately to the right or to the left of the correct one; this seems most often to be the case when the hydrogen ion concentration of the soil expressed in p_H has a value from 5.0 to 5.5. I cannot tell whether the numerical value stated in table 14 may be used at the determination of the hydrogen ion concentration in the above mentioned manner, e. g. also in West Jutland, that differs rather much from the north of Seeland.

As mentioned before, the level of the subsoil water has been measured in the places examined. These measurements will be seen from tables 4—12. As the level of the subsoil water varied in the different localities from 30—100 cm, such different level has of course somewhat influenced the composition of the vegetation. Some species, as e. g. *Carex Goodenoughii* and *Hydrocotyle vulgaris* as a rule only are found where the subsoil water is found in a small depth (about 30 cm). A statistical treatment of the material examined clearly shows that the different levels of the subsoil water influence the average density of the species. When classifying the different localities in 8 classes according

to the level of the subsoil water and when calculating the average density of the species of each class, the following figures will be reached[1]):

Classes of the level of the subsoil water (cm)	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109
Average density of the species	9.3	8.3	7.5	7.1	6.7	4.8	»	7.5

It will be seen that the average density of the species decreases with the increasing depth of the level of the subsoil water; only the last class forms an exception, but in so great depth (100 cm) the subsoil water has presumably no influence or only a small one on the density of the species; it must therefore be supposed that the density in the latter case is determined by other factors.

In case the average level of the subsoil water is calculated for the localities examined in the above mentioned 9 p_H classes, it will appear to vary rather considerably in the different p_H classes, and it is obviously that this fact has influenced the figures given in table 14 for the different p_H classes as regards the average density of the species. These figures are stated here together with the average level of the subsoil water in the different p_H classes.

p_H classes	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9
Average level of the subsoil water	53	40	54	48	66	69	69	50	52
Average density of the species	4.4	5.8	5.9	8.4	8.0	8.3	9.4	10.6	8.7

Especially in the second and fourth p_H class the average level of the subsoil water will be seen to be considerably lower than in the other classes, and the figures of the average density of the species will consequently be too high in the said p_H class. By means of the above summary of the average density of the species in the 8 classes of the level of the subsoil water, the figures of the density in the p_H classes can, however, be corrected, as it will be seen here how great the influence of a certain alteration of the level of the subsoil water has on the density of the species. If the figures of the density of the species

[1]) None of the localities examined occur in the last but one class of the level of the subsoil water.

in the different p_H classes are corrected in such a way that in all the p_H classes an average level of 60—69 cm is calculated, the following figures of the density of the species in the 9 p_H classes will be reached.

p_H classes.....	3.5-3.9	4.0-4.4	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4	6.5-6.9	7.0-7.4	7.5-7.9
Average density of species (corr.).	4.0	4.6	5.5	7.2	8.0	8.3	9.4	10.2	8.3

These figures will be seen to represent a considerably finer graph than those stated above.

In 15 of the localities examined soil samples were taken out to examine the course of the transformation processes of the nitrogen. The result will be seen from the following table. It has not been possible to deduce any connection between the activity of the nitrification and the composition of the vegetation. It will also be seen from the table that there does not exist a closer connection between the hydrogen ion concentration of the

Table 17. The transformation processes of the nitrogen in meadow soils.

Locality	p_H	per cent H_2O	In 1 kilo dry soil was found mg NO_3		In 1 kilo dry soil was found mg NH_4	
			at once	after one month	at once	after one month
No. 78 table 13.....	3.6	87	0	0	15	14
- 77 - 13.....	3.8	82	0	0	12	14
- 5 - 4.....	3.8	80	8	37	20	42
- 6 - 4.....	3.8	85	29	62	6	5
- 12 - 5.....	4.4	80	100	215	40	65
- 14 - 5.....	4.4	55	27	40	8	10
- 16 - 6.....	4.6	48	98	184	5	7
- 25 - 7.....	5.1	52	184	216	7	5
- 32 - 8.....	5.5	56	70	185	4	8
- 43 - 8.....	5.9	30	40	95	4	4
- 45 - 9.....	6.0	41	32	128	3	7
- 48 - 9.....	6.2	52	17	216	not determined	
- 61 - 10.....	6.8	41	85	211	5	3
- 74 - 12.....	7.5	56	22	45	4	3
- 76 - 12.....	7.7	42	30	130	6	5

soil and the intensity of the nitrification. Only in the two first mentioned localities from high moor no nitrification whatever takes place, but the hydrogen ion concentration of the peat in one of these localities is not higher than in the peat in the two following *Molinia* meadows (loc. 5 and 6), in the soil of which the nitrification takes place. Thus nitrification apparently takes place in all meadow soils, even in the most acid ones, while the high moor peat is not nitrificating. Besides it appears from the table that the greatest quantities of ammonia are found in the most acid soils.

In none of the meadow soils examined the mineral plant nutrients have been determined.

The hydrogen ion concentration of the wood soil and the distribution of the wood ground plants.

As mentioned in the section on the meadows it is expedient, when desiring to examine the distribution of the plants in relation to a single factor — in this case the hydrogen ion concentration of the soil — that the habitats examined differ as little as possible as regards all other factors. In the wood ground the conditions of light, as will be known, play a great part as a plant distributing factor. Therefore it would answer the purpose, if the conditions of light were fairly uniform in the localities selected for examination. However, it soon appeared too difficult only to examine localities within certain conditions of light, i. a. because in this case measurements of the light had to be made on a very great number of localities, among which such were to be selected for examination in which the conditions of light were fairly the same. Although however the conditions of light in a number of localities are found to be homogeneous, it is — as mentioned above — by no means given that the vegetation in all the localities are in equilibrium with the conditions of light prevailing at the moment, because these conditions on account of cuttings frequently being made rarely are homogeneous in the same locality for a longer number of years. At the examination, therefore, localities have been included in which the conditions of light were rather different. On some of the localties measurements of the light have been made with Wynnés'

Table 18. Analysis of wood ground habitats and their vegetation.

p_H 3.5—3.9.

Locality no. 84 is situated in Hareskov, no. 92 in Rude Forest, the others in Grib Forest. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil.)

p_H of the soil sample	3.5	3.5	3.5	3.6	3.7	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9	3.9
Locality no.	79	80	81	82	83	84	85	86	87	88	89	90	91	92
Luzula pilosa	»	»	»	»	»	»	»	»	»	»	»	**50**	»	»
Deschampsia flexuosa	**100**	**80**	**100**	»	20	**100**	**100**	**100**	20	20	**100**	**100**	**70**	»
Convallaria majalis	»	»	»	»	»	**100**	»	»	»	»	»	»	»	»
Majanthemum bifolium	»	»	»	»	»	»	»	»	»	»	»	20	»	**100**
Vaccinium myrtillus	**100**	**100**	**100**	**100**	**100**	»	**100**	»	**100**	**100**	»	»	»	»
Pteridium aquilinum	»	»	»	10	»	»	»	»	»	10	»	»	»	»
Carex pilulifera	»	»	»	»	»	»	»	30	»	»	20	10	10	»
Molinia coerulea	»	»	10	»	»	»	»	»	»	»	»	»	»	»
Milium effusum	»	»	»	»	»	»	»	»	»	»	»	»	»	20
Stellaria holostea	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Anemone nemorosa	»	»	»	»	»	»	»	»	»	10	»	»	»	10
Oxalis acetosella	»	»	»	»	»	»	»	»	»	»	»	»	»	20
Vaccinium vitis idaea	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Melampyrum vulgatum	»	10	»	»	10	»	»	»	»	»	»	»	»	»
Galium harcynicum	»	»	»	»	»	»	»	30	»	»	»	»	»	»
Hieracium umbellatum	»	»	»	»	»	»	»	»	»	»	10	»	»	»
Number of species	2	4	3	2	3	2	3	3	2	4	3	4	2	4
Density of species	2.0	2.0	2.1	1.1	1.3	2.0	2.1	1.6	1.2	1.4	1.3	1.8	0.8	1.5
Light percentage	6	»	»	6	»	»	»	»	»	8	»	»	»	8
In the soil sample: pCt. H_2O	40	38	»	45	»	»	»	»	»	25	»	»	20	28
In the soil sample: NO_3 at once	0	0	»	0	»	»	»	»	»	0	»	»	1	1
In the soil sample: — after one month	0	0	»	0	»	»	»	»	»	0	»	»	1	1
In the soil sample: NH_4 at once	10	4	»	10	»	»	»	»	»	2	»	»	3	4
In the soil sample: — after one month	51	107	»	60	»	»	»	»	»	38	»	»	12	10
In the soil sample: K	»	»	»	25	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	0.3	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	27	»	»	»	»	»	»	»	»	»	»

Table 19. Analysis of wood ground habitats and their vegetation.

p_H 4.0—4.4.

Locality nos. 93, 98, 99 and 107 are situated in Grib Forest; nos. 94 and 100 in Rude Forest; nos. 95, 105 and 106 in Tokkekøb enclosure; nos. 96, 101, 102 and 104 in Hareskoven; nos. 97, 111, 112 and 113 in Jonstrup Vang; nos. 103, 108, 109 and 110 in Store Bøgeskov (middle of Seeland) and no. 114 in Ermelunden. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	4.0	4.0	4.0	4.0	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.4	4.4	4.4	4.4
Locality no.	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
Luzula pilosa	40	20	10	**70**	»	30	»	20	»	»	40	**60**	»	»	20	»	»	»	»	»	»	»
Deschampsia flexuosa	**100**	**100**	**100**	**100**	**100**	**50**	»	**100**	»	»	**100**	10	»	»	**100**	»	»	»	»	»	»	»
Melica uniflora	»	»	»	»	»	»	»	»	**100**	**100**	»	»	»	»	»	»	»	»	»	»	10	10
Milium effusum	»	30	40	»	10	»	10	»	10	40	»	30	**70**	40	»	»	»	»	»	»	10	**90**
Convallaria majalis	»	»	»	10	**90**	**100**	»	»	»	**70**	»	»	»	»	»	»	»	»	»	»	»	»
Majanthemum bifolium	»	»	»	**100**	»	»	**100**	»	**100**	»	»	**100**	**100**	**100**	**50**	»	»	»	»	»	»	»
Anemone nemorosa	40	»	**50**	20	**50**	»	**50**	»	10	**60**	»	**50**	20	**100**	40	»	**100**	**100**	**100**	**100**	**100**	40
Oxalis acetosella	10	»	»	»	**90**	»	**80**	»	**60**	**60**	»	10	**100**	**100**	**60**	»	10	»	»	»	**100**	»
Trientalis europaea	10	»	»	»	10	»	»	»	»	»	»	**50**	»	»	**50**	»	»	»	»	»	»	»
Melampyrum vulgatum	»	»	»	»	»	»	»	»	»	»	**50**	»	»	»	»	»	»	»	»	»	»	»
Lamium galeobdolon	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	**100**	**100**	**100**	»	»	»	»
Asperula odorata	»	»	»	»	»	»	»	»	»	30	**50**	»	10	»	»	»	»	»	»	10	»	»
Pteridium aquilinum	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Dryopteris filix mas	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Carex pilulifera	»	10	10	»	30	10	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»
Dactylis glomerata	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Stellaria holostea	»	10	10	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Ranunculus auricomus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10
Viola silvestris	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	30	»
Geranium Robertianum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10
Lathyrus montanus	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Lapsana communis	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	6	5	6	5	8	5	4	2	5	8	4	8	6	4	6	1	3	2	2	2	5	5
Density of species	2.1	1.7	2.2	3.0	3.9	2.0	2.4	1.2	2.8	3.8	2.4	3.2	3.1	3.4	3.2	1.0	2.1	2.0	1.1	1.1	2.5	1.6
Light percentage	8	10	7	»	»	»	3	9	»	»	»	7	3	3	4	»	»	»	»	»	»	»
In the soil sample: pCt. H_2O	15	29	33	»	»	»	38	25	»	»	»	51	40	22	26	»	»	»	»	»	»	»
In the soil sample: NO_3 at once	0	0	0	»	»	»	0	0	»	»	»	0	0	0	1	»	»	»	»	»	»	»
In the soil sample: — after one month	0	0	0	»	»	»	190	0	»	»	»	13	2	0	2	»	»	»	»	»	»	»
In the soil sample: NH_4 at once	1	27	14	»	»	»	7	2	»	»	»	6	99	2	4	»	»	»	»	»	»	»
In the soil sample: — after one month	10	82	70	»	»	»	212	30	»	»	»	105	150	40	31	»	»	»	»	»	»	»
In the soil sample: K	»	»	»	»	»	»	»	»	»	»	»	28	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	»	»	»	»	»	0.2	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	»	»	»	»	»	25	»	»	»	»	»	»	»	»	»	»

Table 20. Analysis of wood ground habitats and their vegetation.

P_H 4.5—4.9.

Locality no. 115 is situated in Jægersborg deer-park, nos. 116, 120, 121, 122, 127, 131, 132, 135 and 137 in Hareskoven, nos. 117, 123, 124, 125, 126, 130 and 134 in Grib Forest, nos. 118 and 136 in Store Bøgeskov; nos. 119, 128 and 133 in Ermelunden and no. 129 in Jonstrup Vang. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.9	4.9	4.9
Locality no.	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137
Melica uniflora	»	»	100	»	»	»	100	»	»	100	»	100	100	»	»	100	»	»	»	100	»	100	100
Milium effusum	»	»	»	»	»	30	80	»	»	»	»	80	»	»	10	»	»	»	»	»	»	80	20
Majanthemum bifolium	»	»	»	»	»	»	»	»	»	»	»	40	»	»	»	70	»	»	»	»	»	»	»
Stellaria holostea	»	»	»	»	»	»	»	»	»	»	»	40	»	»	»	30	»	»	10	»	»	40	70
Anemone nemorosa	100	100	60	100	100	100	60	100	»	»	100	»	100	100	100	30	100	100	100	30	100	100	»
Viola silvestris	»	»	50	»	»	»	10	»	»	»	10	»	»	»	»	»	20	»	»	»	»	30	»
Mercurialis perennis	»	»	»	»	»	»	»	»	»	50	»	10	»	»	»	»	»	»	»	»	»	»	»
Oxalis acetosella	100	»	30	100	»	100	30	»	100	»	100	»	80	»	10	90	»	100	90	30	50	100	80
Geranium Robertianum	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	100	»
Lamium galeobdolon	»	»	»	100	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Asperula odorata	10	»	10	»	»	»	50	»	100	»	30	100	50	»	»	50	»	»	»	10	100	90	40
Carex silvatica	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»
Deschampsia caespitosa	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»
Gagea lutea	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Ranunculus auricomus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»	»	»
Anemone hepatica	»	»	»	»	»	»	20	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»
— ranunculoides	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Corydallis cava	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
— intermedia	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»
Veronica montana	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»
Stachys silvaticus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»
Lapsana communis	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	10	»	»	»	»
Number of species	3	1	5	4	4	3	7	1	2	2	4	7	5	1	4	7	2	3	6	4	3	10	5
Density of species	2.1	1.0	2.5	3.1	1.5	2.2	3.5	1.0	2.0	1.5	2.4	3.8	3.4	1.0	1.3	3.8	1.2	2.1	2.4	1.7	2.5	6.6	3.1
Light percentage	»	4	3	»	»	»	10	»	»	»	»	»	»	»	4	»	»	»	»	»	»	»	»
In the soil sample: per cent H_2O	»	21	26	»	»	»	26	»	»	»	»	»	»	»	22	»	»	»	»	»	»	»	»
In the soil sample: NO_3 at once	»	25	13	»	»	»	10	»	»	»	»	»	»	»	15	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	382	385	»	»	»	412	»	»	»	»	»	»	»	188	»	»	»	»	»	»	»	»
In the soil sample: NH_4 at once	»	6	11	»	»	»	12	»	»	»	»	»	»	»	3	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	16	57	»	»	»	16	»	»	»	»	»	»	»	2	»	»	»	»	»	»	»	»
In the soil sample: K	»	»	»	»	»	»	24	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	2	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	42	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»

Table 21. Analysis of wood ground habitats and their vegetation.

Locality nos. 138, 140, 147, 148, 149, 152, 158, 161, 163 and 164 are situated in Grib For—5.4.
165 in Hareskoven, nos. 145, 146, 150 and 155 in Ermelunden, no. 157 in Nørreskov near est, nos. 139, 143, 151, 154, 159, 162 and 168 in Store Bøgeskov, nos. 141, 142, 153, 156 and
Farum, no. 160 and 166 in Jægersborg deer-park and no. 167 in Rude Forest. (The quan-
tity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil)

pH of the soil sample	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.1
Locality no.	138	139	140	141	142	143	144	145	146	147	148
Dryopteris pulchella	»	»	»	»	100	»	»	»	»	»	»
Melica uniflora	100	»	»	»	»	»	100	»	»	»	»
Milium effusum	»	»	20	»	»	»	20	»	»	»	100
Hordeum europaeum	»	»	»	»	»	»	»	»	»	»	»
Majanthemum bifolium	»	»	50	»	»	»	»	»	»	»	»
Stellaria holostea	»	»	10	»	»	»	70	»	»	»	»
Anemone nemorosa	60	10	»	80	100	100	100	100	100	100	50
Corydallis cava	»	50	»	»	»	»	»	»	10	»	»
Viola silvestris	20	»	10	»	20	»	10	»	»	40	10
Mercurialis perennis	»	100	»	»	»	»	»	»	»	»	»
Oxalis acetosella	40	»	100	90	80	100	100	»	»	100	60
Lamium galeobdolon	»	»	»	»	»	100	»	»	»	»	»
Asperula odorata	100	»	100	100	10	30	70	»	»	50	20
Carex silvatica	»	»	»	»	»	»	»	»	»	»	»
Poa nemoralis	»	»	10	»	»	»	»	»	»	»	»
Deschampsia caespitosa	»	»	10	»	»	»	»	»	»	»	»
Gagea lutea	»	»	»	»	»	»	»	»	20	»	»
Polygonatum multiflorum	»	»	»	»	»	»	»	»	»	»	»
Urtica dioeca	»	»	»	»	»	»	»	»	»	»	»
Anemone hepatica	10	»	»	»	»	»	»	»	»	»	»
Geranium Robertianum	»	»	»	»	»	»	»	»	»	»	»
Vicia sepium	20	»	»	20	»	»	10	»	»	10	»
Veronica montana	»	»	»	»	»	»	»	»	»	»	»
Stachys silvaticus	»	»	»	»	»	»	»	»	»	»	»
Number of species	7	3	8	4	5	4	8	1	3	5	5
Density of species	3.5	1.6	3.1	2.9	3.1	3.3	4.8	1.0	1.3	3.0	2.4
Light percentage	»	»	»	»	»	»	»	»	6	»	»
In the soil sample: per cent H_2O	»	»	»	20	»	»	»	»	23	»	»
In the soil sample: NO_3 at once	»	»	»	37	»	»	»	»	12	»	»
In the soil sample: — after one month	»	»	»	209	»	»	»	»	95	»	»
In the soil sample: NH_4 at once	»	»	»	7	»	»	»	»	5	»	»
In the soil sample: — after one month	»	»	»	9	»	»	»	»	5	»	»
In the soil sample: K	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	»	»	»	»	»

pH of the soil sample	5.1	5.1	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.4
Locality no.	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
Dryopteris pulchella	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Melica uniflora	100	»	100	100	30	20	»	»	»	100	»	100	100	»	100	100	100	»	»	»
Milium effusum	»	»	»	»	100	»	20	10	»	»	»	»	»	»	»	»	60	»	»	»
Hordeum europaeum	»	»	»	»	»	80	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Majanthemum bifolium	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Stellaria holostea	»	»	»	»	»	»	»	»	»	»	40	»	»	»	»	»	»	»	»	»
Anemone nemorosa	50	100	»	»	»	100	100	20	80	60	100	50	20	»	70	100	40	100	»	100
Corydallis cava	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Viola silvestris	»	»	»	10	»	»	»	»	»	»	60	»	»	20	»	»	»	»	»	»
Mercurialis perennis	»	»	»	20	»	60	»	»	»	100	»	»	»	»	»	»	»	»	»	»
Oxalis acetosella	»	100	20	»	60	100	100	100	100	20	100	100	30	30	100	30	100	»	30	100
Lamium galeobdolon	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	»	»	»	100
Asperula odorata	60	»	90	20	»	20	»	»	100	»	100	50	50	20	»	70	50	»	100	»
Carex silvatica	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Poa nemoralis	»	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»
Deschampsia caespitosa	»	»	»	»	»	»	»	10	»	»	»	»	»	»	10	»	»	»	»	»
Gagea lutea	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Polygonatum multiflorum	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Urtica dioeca	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Anemone hepatica	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»	»	»	»	»
Geranium Robertianum	»	»	»	»	»	40	»	»	»	»	»	»	»	20	»	»	»	»	»	»
Vicia sepium	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Veronica montana	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Stachys silvaticus	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	3	2	3	5	3	9	3	5	3	4	7	4	6	6	4	4	5	1	2	3
Density of species	2.1	2.0	2.1	1.6	1.9	4.4	2.2	1.7	2.8	2.8	4.2	3.0	2.2	2.1	2.8	3.0	3.5	1.0	1.3	3.0
Light percentage	»	»	»	»	»	»	»	»	2	»	»	»	10	»	»	»	»	»	5	»
In the soil sample: per cent H_2O	»	»	»	»	»	»	»	»	23	»	»	»	19	»	»	»	»	»	32	»
In the soil sample: NO_3 at once	»	»	»	»	»	»	»	»	0	»	»	»	9	»	»	»	»	»	5	»
In the soil sample: — after one month	»	»	»	»	»	»	»	»	191	»	»	»	240	»	»	»	»	»	242	»
In the soil sample: NH_4 at once	»	»	»	»	»	»	»	»	6	»	»	»	5	»	»	»	»	»	20	»
In the soil sample: — after one month	»	»	»	»	»	»	»	»	7	»	»	»	30	»	»	»	»	»	69	»
In the soil sample: K	»	»	»	»	»	»	»	»	»	»	»	»	17	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	»	»	»	»	»	»	2	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	»	»	»	»	»	»	40	»	»	»	»	»	»	»

Table 22. Analysis of wood ground habitats and their vegetation.

p_H 5·5—5·9.

Locality nos. 169 and 170 are situated in Allindelille Fredskov, nos. 171, 175, 181, 186 and 188 in Hareskoven, nos. 172, 182, 184 and 187 in Store Bøgeskov, nos. 173, 174 and 180 in Bognæs Storskov, nos. 176 and 179 in Geels Forest, no. 177, 183, 185 and 189 in Grib Forest and no. 178 in Ermelunden. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg pr. one kilo dry soil).

p_H of the soil sample	5·5	5·5	5·5	5·5	5·5	5·5	5·5	5·5	5·6	5·6	5·6	5·6	5·6	5·6	5·7	5·7	5·8	5·8	5·8	5·9	5·9
Locality no.	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189
Melica uniflora	»	»	80	»	»	»	10	100	100	»	»	»	»	»	100	100	»	»	»	»	40
Milium effusum	»	»	90	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Hordeum europaeum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	50	»	»
Allium ursinum	»	»	»	»	100	100	»	»	»	»	»	100	»	»	»	»	»	»	»	»	»
Anemone nemorosa	»	10	40	100	»	»	100	60	»	»	»	»	100	100	40	100	»	100	100	»	»
Mercurialis perennis	»	»	»	100	»	»	»	»	100	100	100	»	»	»	10	»	100	»	»	»	100
Oxalis acetosella	90	20	80	»	»	»	»	100	»	»	»	»	»	100	»	100	»	30	100	»	»
Geranium Robertianum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	80	»	»	»	»	»
Aegopodium podagraria	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	100	»
Lamium galeobdolon	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	100	»	»	100	»	»
Asperula odorata	100	100	20	»	»	»	100	90	90	»	»	»	»	80	»	»	»	100	»	»	»
Pteridium aquilinum	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»
Luzula pilosa	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Carex silvatica	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»
Festuca gigantea	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Poa nemoralis	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Deschampsia caespitosa	»	10	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Urtica dioeca	»	»	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»	10	»
Stellaria holostea	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	20	10	»
Anemone hepatica	»	»	»	»	»	»	»	»	»	»	»	»	»	»	30	20	»	»	»	»	»
Viola silvestris	40	40	20	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»
Vicia sepium	40	»	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	10	»	»	»
Circaea lutetiana	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Pirola minor	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Pulmonaria officinalis	»	»	»	»	»	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»
Stachys silvaticus	»	»	»	»	»	»	»	»	»	»	30	»	»	»	»	»	30	»	»	»	»
Ajuga reptans	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	7	8	7	2	1	1	3	5	7	2	4	1	1	4	4	7	2	4	5	3	2
Density of species	3.0	2.1	3.4	2.0	1.0	1.0	2.1	3.6	3.8	1.1	1.5	1.0	1.0	3.8	1.8	6.0	1.3	2.4	3.7	1.2	1.4
Light percentage	»	»	»	»	»	»	7	3	»	»	»	»	6	»	»	»	»	3	»	»	»
In the soil sample: per cent H_2O	»	»	»	»	»	»	22	28	»	»	»	»	21	»	»	»	»	»	»	»	»
In the soil sample: NO_3 at once	»	»	»	»	»	»	3	0	»	»	»	»	11	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	»	»	»	»	»	202	117	»	»	»	»	89	»	»	»	»	»	»	»	»
In the soil sample: NH_4 at once	»	»	»	»	»	»	6	5	»	»	»	»	8	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	»	»	»	»	»	40	12	»	»	»	»	17	»	»	»	»	»	»	»	»
In the soil sample: K	»	»	»	»	»	»	15	»	»	»	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	2	»	»	»	»	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	45	»	»	»	»	»	»	»	»	»	»	»	»	»	»

Table 23. Analysis of wood ground habitats and their vegetation.

p_H 6.0—6.4.

Locality nos. 190, 200 and 201 are situated in Jægersborg deer-park nos. 191, 192, 197, 202, 210 and 213 in Grib Forest, nos. 193, 207 and 214 in the Forest at Wedellsborg at Fünen, nos. 194 and 212 in Bognæs Storskov, nos. 195 and 199 in Boserup wood, no. 196 i Jonstrup Vang, no. 198 in Hareskoven, nos. 203, 209, 211, 215 and 216 in Store Bøgeskov, no. 204 in Nørreskov near Farum, nos. 205 og 206 in Resle Forest in Falster and no. 208 i Bognæs Vesterskov. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.1	6.1	6.1	6.2	6.2	6.2	6.2	6.2	6.3	6.3	6.3	6.3	6.3	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Locality no.	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216
Melica uniflora	»	»	10	»	»	100	»	»	»	»	»	40	»	»	10	»	»	»	»	»	»	10	»	»	»	»	80
Brachypodium silvaticum	100	»	»	»	»	»	»	»	»	»	100	100	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Hordeum europaeum	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	»	»	»	40	»	100	»	»	»	»	100
Allium ursinum	»	»	»	»	100	»	»	»	»	»	»	»	»	»	»	100	100	10	100	»	»	»	100	»	»	»	»
Anemone nemorosa	»	»	»	100	»	100	80	»	100	100	»	»	»	30	90	»	»	»	»	100	»	100	»	»	100	»	100
Mercurialis perennis	60	100	»	»	»	»	100	100	»	»	40	90	100	100	»	»	»	100	»	»	»	50	»	100	»	»	30
Oxalis acetosella	100	30	»	20	»	100	»	»	»	»	»	»	»	60	»	»	»	»	»	60	»	100	»	»	»	»	20
Aegopodium podagraria	»	»	100	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	»	»	»	»
Lamium galeobdolon	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	»	»	»	100	»
Asperula odorata	»	»	»	»	»	»	»	»	»	20	»	»	»	30	100	»	»	»	»	»	»	20	»	»	»	»	10
Dactylis glomerata	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Bromus ramosus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»	»	»	»
Festuca gigantea	»	»	»	»	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Deschampsia caespitosa	»	»	»	»	»	»	»	»	»	»	20	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»
Milium effusum	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Agropyrum caninum	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Polygonatum multiflorum	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Urtica dioeca	20	40	»	»	»	»	»	»	»	»	30	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Stellaria holostea	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	40	»	»
Ranunculus auricomus	»	»	»	»	»	20	10	»	»	10	10	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Anemone hepatica	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»
— ranunculoides	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Corydallis intermedia	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»
Viola silvestris	»	»	»	10	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	30	»	»	10	»	»
Geranium Robertianum	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»
Geum urbanum	»	20	»	10	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	20	»	»	40	»	»
Circaea lutetiana	»	»	»	»	»	»	»	»	»	»	30	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Sanicula europaea	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»
Primula elatior	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Veronica montana	»	»	»	»	»	»	»	»	»	»	»	»	»	40	»	»	»	»	»	»	»	»	»	»	»	»	20
Stachys silvaticus	»	»	»	»	»	»	10	»	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Campanula trachelium	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»
Lapsana communis	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	4	6	2	7	1	5	5	1	1	3	9	5	2	8	4	1	1	3	1	4	1	12	1	1	5	1	7
Density of species	2.8	2.3	1.1	1.9	1.0	3.4	2.3	1.0	1.0	1.3	2.8	2.8	1.2	3.8	2.1	1.0	1.0	1.2	1.0	3.0	1.0	4.8	1.0	1.0	2.1	1.0	3.6
Light percentage	»	»	»	»	2	9	7	»	3	6	»	»	»	10	3	»	»	»	6	»	»	10	»	»	»	»	»
In the soil sample: per cent H_2O	»	»	»	»	16	18	26	»	»	30	»	»	»	»	31	»	»	»	19	»	»	»	»	»	»	»	»
In the soil sample: NO_3 at once	»	»	»	»	21	23	8	»	»	24	»	»	»	»	0	»	»	»	14	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	»	»	»	114	100	215	»	»	89	»	»	»	»	269	»	»	»	112	»	»	»	»	»	»	»	»
In the soil sample: NH_4 at once	»	»	»	»	5	5	5	»	»	5	»	»	»	»	9	»	»	»	1	»	»	»	»	»	»	»	»
In the soil sample: — after one month	»	»	»	»	3	3	2	»	»	3	»	»	»	»	12	»	»	»	2	»	»	»	»	»	»	»	»
In the soil sample: K	»	»	»	»	33	»	»	»	»	46	»	»	»	»	»	»	»	»	24	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	3	»	»	»	»	8	»	»	»	»	»	»	»	»	12	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	79	»	»	»	»	125	»	»	»	»	»	»	»	»	207	»	»	»	»	»	»	»	»

Table 24. Analysis of wood ground habitats and their vegetation.

p_H 6.5—6.9.

Locality nos. 217 and 225 are situated in Ermelunden, nos. 218 and 222 in the Forest at Wedellsborg in Fünen, nos. 219 and 226 in Jonstrup Vang, no. 220 in Boserup wood, nos. 221 and 230 in Bognæs Storskov, nos. 223 and 231 i Hareskoven, no. 224 in Nordskoven near Guldborg (Falster), no. 227 in Grib Forest and nos. 228, 229, 232 and 233 in Store Bøgeskov. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	6.5	6.5	6.5	6.6	6.6	6.6	6.6	6.7	6.7	6.7	6.8	6.8	6.8	6.8	6.9	6.9	6.9
Locality no.	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233
Melica uniflora	»	»	10	»	»	»	100	»	»	»	»	50	»	10	»	»	»
Brachypodium silvaticum	»	»	»	100	100	»	»	»	»	»	»	»	»	»	»	»	»
Hordeum europaeum	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»	»	100
Allium ursinum	»	100	»	»	»	100	»	»	»	»	»	»	»	100	»	»	»
Urtica dioeca	»	»	10	»	50	»	»	»	»	»	30	»	»	»	20	»	»
Ficaria verna	40	»	»	»	90	»	»	»	»	»	»	»	»	»	»	»	»
Anemone nemorosa	100	»	100	»	100	»	60	100	100	100	70	100	100	»	»	100	»
Mercurialis perennis	»	20	100	»	»	»	40	100	100	100	100	60	»	»	»	100	»
Oxalis acetosella	»	»	»	40	50	»	100	»	80	»	»	»	20	»	»	»	100
Sanicula europaea	10	»	»	10	»	»	»	50	»	»	»	»	»	»	»	»	»
Aegopodium podagraria	»	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»
Veronica chamaedrys	»	»	»	50	»	»	»	»	»	»	»	»	»	»	»	»	»
Asperula odorata	»	»	»	»	»	»	50	»	»	»	20	40	»	»	»	10	50
Dryopteris filix mas	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»
Carex silvatica	»	»	»	»	»	»	»	20	»	»	»	»	»	»	»	»	»
Dactylis glomerata																	
Deschampsia caespitosa	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Milium effusum	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»
Agropyrum caninum	»	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»
Stellaria media	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Anemone hepatica	»	»	»	»	»	»	»	20	»	»	»	»	30	»	»	»	»
Viola silvestris	40	»	»	40	30	»	»	»	»	»	»	20	»	»	»	»	40
Geranium Robertianum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	40	»	»
Geum urbanum	»	»	»	30	40	»	»	»	»	»	»	»	»	»	»	»	»
Vicia sepium	»	»	»	»	»	»	»	»	»	»	20	30	20	»	»	»	»
Epilobium montanum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»
Circaea lutetiana	»	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»
Primula elatior	»	»	»	»	»	»	»	20	»	»	»	»	»	»	»	»	»
Number of species	4	2	6	7	8	2	5	6	3	2	6	6	5	2	5	3	4
Density of species	1.9	1.2	2.4	2.9	4.8	1.1	3.5	3.1	2.8	2.0	2.5	3.0	2.7	1.1	1.9	2.1	2.9
Light percentage	»	»	8	9	10	»	11	»	»	10	»	»	»	3	»	»	»
In the soil sample: per cent H_2O	»	»	30	»	»	»	21	»	»	28	»	»	»	25	»	»	»
In the soil sample: NO_3 at once	»	»	70	»	»	»	6	»	»	40	»	»	»	20	»	»	»
In the soil sample: — after one month	»	»	222	»	»	»	185	»	»	310	»	»	»	111	»	»	»
In the soil sample: NH_4 at once	»	»	3	»	»	»	6	»	»	3	»	»	»	1	»	»	»
In the soil sample: — after one month	»	»	3	»	»	»	4	»	»	3	»	»	»	2	»	»	»
In the soil sample: K	»	»	»	»	»	»	30	»	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	»	»	»	4	»	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	»	»	»	102	»	»	»	»	»	»	»	»	»	»

Table 25. Analysis of wood ground habitats and their vegetation.

P_H 7.0—7.4.

Locality nos. 234, 235, 241, 242 and 244 are situated in Store Bøgeskov, nos. 236 and 247 in Nørreskov near Farum, nos. 237, 238, 239 and 240 in Allindelille Fredskov, no. 243 in Boserup wood, no. 245 in Ermelunden and no. 246 in Bognæs Storskov. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	7.0	7.0	7.1	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.4	7.4	7.4	7.4
Locality no.	234	235	236	237	238	239	240	241	242	243	244	245	246	247
Melica uniflora	»	10	»	20	»	100	»	»	»	10	60	»	»	»
Brachypodium silvaticum	»	»	100	»	»	»	»	»	»	»	»	»	»	100
Hordeum europaeum	100	100	»	70	70	»	100	100	100	»	100	»	»	»
Allium ursinum	»	»	»	»	»	»	»	»	»	»	»	»	100	»
Ficaria verna	»	»	»	»	»	»	»	»	»	100	»	»	»	40
Anemone hepatica	»	30	»	80	80	80	80	40	»	20	»	»	»	»
— nemorosa	»	100	»	70	»	»	»	100	100	100	100	»	»	»
Viola silvestris	10	40	30	40	10	80	50	60	10	»	10	»	»	»
Mercurialis perennis	»	100	»	100	100	100	20	»	100	100	»	»	20	»
Oxalis acetosella	100	30	10	»	10	»	90	90	40	»	100	»	»	20
Geum urbanum	»	»	20	10	»	»	»	»	»	50	»	50	»	40
Vicia sepium	»	»	30	»	»	»	50	»	»	»	20	»	»	40
Hedera helix	»	»	»	80	40	50	»	»	»	»	»	»	»	»
Aegopodium podagraria	»	»	»	»	»	»	»	»	»	80	»	100	»	»
Adoxa moschatellina	»	»	»	»	»	»	»	»	»	100	»	»	»	»
Asperula odorata	»	10	»	20	40	40	90	100	10	»	»	10	»	»
Festuca gigantea	»	»	»	»	20	40	»	»	»	»	»	»	»	»
Poa nemoralis	»	»	»	»	20	»	»	»	»	»	»	10	»	»
Deschampsia caespitosa	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Agropyrum caninum	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Polygonatum multiflorum	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Paris quadrifolius	»	»	»	»	»	»	»	»	»	»	»	»	10	10
Urtica dioeca	»	»	10	»	»	»	10	»	»	»	»	»	»	»
Ranunculus auricomus	»	»	»	10	10	»	»	»	»	»	»	»	10	»
Actaea spicata	»	»	»	»	»	»	»	»	»	20	»	»	»	»
Corydallis cava	»	»	»	»	»	»	»	»	»	»	40	»	»	»
Viola mirabilis	»	»	»	»	10	»	»	»	»	»	»	»	»	»
Geranium Robertianum	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Fragaria vesca	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Rubus saxatilis	»	»	»	»	»	»	»	»	»	»	10	»	»	»
Lathyrus vernus	»	»	40	20	20	40	40	»	»	20	»	30	»	»
Sanicula europaea	»	»	»	»	10	»	»	»	»	10	»	»	»	»
Anthriscus silvester	»	»	»	»	»	»	»	»	»	20	»	»	»	»
Primula elatior	»	»	»	»	20	»	10	»	»	»	»	»	»	»
Pulmonaria officinalis	»	»	»	»	»	»	»	»	10	»	10	»	»	»
Veronica montana	»	»	10	»	»	»	»	»	»	»	»	»	»	»
Stachys silvaticus	»	»	»	»	»	»	»	»	»	10	»	»	»	»
Campanula trachelium	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	3	8	8	11	16	8	12	6	8	13	9	5	4	6
Density of species	2.1	4.2	2.5	5.2	4.8	5.3	5.6	4.9	3.8	6.4	4.5	2.0	1.4	2.5
Light percentage	»	10	»	»	»	6	»	»	9	»	»	»	4	»
In the soil sample: per cent H_2O	»	»	»	»	»	»	»	»	»	»	»	»	24	»
In the soil sample: NO_3 at once	»	»	»	»	»	»		»	»	»	»	»	15	»
In the soil sample: — after one month	»	»	»	»	»	»		»	»	»	»	»	122	»
In the soil sample: NH_4 at once	»	»	»	»	»	»		»	»	»	»	»	2	»
In the soil sample: — after one month	»	»	»	»	»	»	»	»	»	»	»	»	1	»
In the soil sample: K	»	»	»	»	»	»	»	»	»	»	»	»	114	»
In the soil sample: PO_4	»	»	»	»	»	»	»	»	»	»	»	»	4	»
In the soil sample: Ca	»	»	»	»	»	»	»	»	»	»	»	»	1275	»

Table 26. Analysis of wood ground habitats and their vegetation.

P_H 7·5—7·9.

Locality nos. 248 and 249 are situated in Ermelunden, nos. 250 and 255 in Nørreskov near Farum, no. 251 in Bjerge Forest near Skorping, no. 252 in Jægersborg deer-park, no. 253 in Hareskoven, nos. 254, 260 and 266 in Store Bøgeskov, nos. 256, 257 and 258 in Kastrup Forest near Allindelille, nos. 259, 261 and 262 in Boserup wood and nos. 263, 264 and 265 in Bognæs Storskov. (The quantity of NO_3, NH_4, K, PO_4 and Ca in the soil is expressed in mg per one kilo dry soil).

p_H of the soil sample	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.9
Locality no.	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266
Brachypodium silvaticum	»	»	100	»	100	»	»	100	»	10	»	60	»	100	80	100	»	»	»
Hordeum europaeum	»	»	»	»	»	»	100	»	30	40	50	»	100	»	»	»	»	»	100
Allium ursinum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	100	»	»
Anemone hepatica	»	»	»	100	»	»	70	40	100	80	»	»	20	»	»	30	»	»	»
— nemorosa	20	»	»	50	100	»	100	»	60	70	30	100	»	60	100	»	»	30	»
Viola mirabilis	»	»	»	»	»	»	»	»	»	»	»	80	»	20	80	»	»	»	»
Mercurialis perennis	100	100	»	50	60	100	»	»	100	100	100	50	»	»	»	»	»	100	100
Oxalis acetosella	»	»	»	»	»	»	20	»	»	10	»	»	100	»	»	»	»	»	»
Hedera helix	»	»	»	80	»	»	»	»	»	100	»	»	»	»	»	»	»	»	»
Sanicula europaea	»	»	»	30	»	»	»	»	»	»	»	»	»	80	30	30	»	»	»
Lamium galeobdolon	»	»	»	»	»	»	»	»	»	»	»	»	80	»	»	»	»	»	»
Ajuga reptans	»	»	»	»	»	»	50	»	»	»	»	»	60	»	»	»	»	»	»
Asperula odorata	»	»	10	»	»	»	»	30	10	30	30	»	80	»	»	»	»	»	60
Carex digitata	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
— silvatica	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10	10	»	»	»
Dactylis glomerata	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Festuca gigantea	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Poa nemoralis	»	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»
Melica unifiora	»	»	»	»	20	»	»	»	»	»	»	»	»	»	10	»	»	»	30
— nutans	»	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Convallaria majalis	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»
Paris quadrifolius	»	»	»	»	»	»	»	»	»	20	»	»	»	»	»	»	»	»	»
Cypripedilum calceolus	»	»	»	40	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Cephalanthera rubra	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Urtica dioeca	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Stellaria holostea	»	»	»	»	»	»	»	»	»	»	»	10	»	»	»	»	»	»	»
Ficaria verna	»	»	»	»	»	»	»	»	»	»	»	»	»	»	40	20	»	»	»
Actaea spicata	»	»	»	10	»	»	»	»	»	10	»	»	»	10	»	»	»	»	»
Corydallis cava	10	»	»	»	»	»	»	»	»	»	»	»	»	»	20	»	»	»	»
Viola silvestris	»	»	»	10	20	»	10	»	»	»	»	»	»	30	10	»	»	»	40
Geum urbanum	»	20	»	»	30	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Rubus saxatilis	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Vicia sepium	»	»	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»
Circaea lutetiana	»	»	»	»	10	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Pulmonaria officinalis	»	»	»	»	»	»	»	»	»	10	»	20	»	40	20	»	»	»	»
Veronica montana	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Stachys silvaticus	»	»	10	»	»	»	»	40	»	»	»	»	»	»	»	»	»	»	»
Lactuca muralis	»	»	»	»	20	»	»	»	»	»	»	»	»	»	»	»	»	»	»
Number of species	3	2	4	13	9	1	7	4	6	11	4	7	6	8	10	5	1	2	5
Density of species	1.3	1.2	1.3	4.6	3.7	1.0	3.6	2.1	3.1	4.8	2.1	3.3	4.4	3.5	4.0	1.9	1.0	1.3	3.3
Light percentage	»	»	»	6	»	»	»	»	7	5	5	»	»	»	»	4	2	6	»
In the soil sample: per cent H_2O	»	»	»	35	»	»	»	»	32	28	26	»	»	»	»	28	26	25	»
In the soil sample: NO once$_3$ at	»	»	»	19	»	»	»	»	12	23	20	»	»	»	»	23	31	10	»
In the soil sample: — after one month	»	»	»	109	»	»	»	»	152	152	92	»	»	»	»	240	70	96	»
In the soil sample: NH_4 at once	»	»	»	1	»	»	»	»	1	0	0	»	»	»	»	0	4	0	»
In the soil sample: — after one month	»	»	»	1	»	»	»	»	1	0	0	»	»	»	»	1	2	0	»
In the soil sample: K	»	»	»	83	»	»	»	»	»	12	»	»	»	»	»	»	»	»	»
In the soil sample: PO_4	»	»	»	0.2	»	»	»	»	»	16	»	»	»	»	»	»	»	»	»
In the soil sample: Ca	»	»	»	2311	»	»	»	»	»	1747	»	»	»	»	»	»	»	»	»

Table 27. The average frequency of the wood plants in the p_H classes.

p_H classes	3.5—3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	6.5—6.9	7.0—7.4	7.5—7.9	Number of occurrences
Vaccinium myrtillus	100	»	»	»	»	»	»	»	»	8
Deschampsia flexuosa	76	86	»	»	»	»	»	»	»	22
Carex pilulifera	18	14	»	»	»	»	»	»	»	9
Luzula pilosa	50	34	»	»	10	»	»	»	»	11
Convallaria majalis	100	68	»	»	»	»	»	»	10	6
Majanthemum bifolium	60	93	55	30	»	»	»	»	»	13
Trientalis europaea	»	30	»	»	»	»	»	»	»	4
Oxalis acetosella	20	62	74	76	78	61	65	54	43	87
Anemone nemorosa	10	61	88	76	77	91	94	95	65	113
Lamium galeobdolon	»	100	100	100	100	100	»	»	80	13
Melica uniflora	»	55	100	88	76	42	43	40	20	51
Milium effusum	20	35	50	47	50	10	10	»	»	29
Asperula odorata	»	25	53	61	85	36	34	40	36	69
Hordeum europaeum	»	»	»	80	75	85	100	93	70	23
Mercurialis perennis	»	»	30	70	87	81	80	80	87	53
Viola silvestris	»	20	24	22	27	18	34	34	20	45
Allium ursinum	»	»	»	»	100	85	100	100	100	14
Aegopodium podagraria	»	»	»	»	55	100	100	90	»	7
Brachypodium silvaticum	»	»	»	»	»	100	100	100	81	15
Ficaria verna	»	»	»	»	»	»	65	70	30	6
Geum urbanum	»	»	»	»	»	20	35	34	23	16
Anemone hepatica	»	»	15	15	15	10	25	59	63	23
Sanicula europaea	»	»	»	»	»	20	23	30	43	16
Average number of species	2.9	4.6	4.0	4.4	3.8	3.7	4.5	8.4	5.7	
— density of species	1.6	2.4	2.4	2.6	2.3	1.9	2.5	3.9	2.7	

Tabel 28. Wood ground plants. Number of occurrences with frequency of 50 and more than 50 in the p_H classes (per cent).

p_H classes	3.5—3.9	4.0—4.4	4.5—4.9	5.0—5.4	5.5—5.9	6.0—6.4	6.5—6.9	7.0—7.4	7.5—7.9	Number of occurrences
Vaccinium myrtillus	**100**	»	»	»	»	»	»	»	»	8
Deschampsia flexuosa	45	**55**	»	»	»	»	»	»	»	18
Convallaria majalis	**57**	43	»	»	»	»	»	»	»	4
Majanthemum bifolium	20	**40**	20	20	»	»	»	»	»	10
Oxalis acetosella	»	**15**	**15**	14	**15**	13	13	9	7	58
Anemone nemorosa	»	10	13	12	11	13	**15**	**15**	11	92
Lamium galeobdolon	»	**20**	**20**	**20**	**20**	**20**	»	»	»	12
Melica uniflora	»	12	**23**	20	17	8	12	9	»	33
Milium effusum	»	11	**31**	27	**31**	»	»	»	»	9
Asperula odorata	»	7	16	20	**25**	6	11	7	8	36
Hordeum europaeum	»	»	»	**19**	**19**	14	**19**	**19**	12	20
Mercurialis perennis	»	»	9	14	16	15	14	14	**18**	44
Allium ursinum	»	»	»	»	**21**	17	**21**	**21**	**21**	13
Aegopodium podagraria	»	»	»	»	14	**29**	**29**	**29**	»	6
Brachypodium silvaticum	»	»	»	»	»	**26**	**26**	**26**	23	14
Anemone hepatica	»	»	»	»	»	»	»	**50**	**50**	8

actinometre, and the values of light here oscillated between 2 and 11 per cent. of the free day light. In the localities, where the light was not measured the conditions of light have presumably been within the same limits.

All the localities examined are situated in forests of beech-trees. Furthermore the soil in all the localities is a mineral soil. Localities have been avoided, where the subsoil water is found in inconsiderable depth and where the soil consequently is rather moist. I have also avoided localities with very dry soil. The formations examined, therefore, all are found in habitats with fairly uniform conditions of moisture, which also will appear from the values of the water contents[1]) of the soil, given in the following tables for some of the localities examined.

The investigations were made during the years 1917—1920. The result of the analysis will appear from the tables 18—26, in which the formations examined are arranged according to the hydrogen ion concentration[2]) of the soil on the habitats and on the whole in the same manner as in the tables on the meadow localities (tables 4—12). As will be seen from the tables the majority of the localities are situated in the north of Seeland, but also localities from the middle of Seeland, from Fünen, Lolland-Falster and Jutland are included in the investigations. For each locality the species found at the formation-statistical ana-

[1]) An exact basis for a comparison of the conditions of moisture in the different habitats will not be obtained by these figures, for although the soil samples — as mentioned before — were neither selected in specially dry periods nor in specially moist ones, they were not selected at the same time on all the localities. Even if this had been the case, rainfalls in some of the localities a short time before the samples were taken out might have caused that the soils as regards the conditions of moisture could not be compared. Finally, it must be borne in mind that only a fraction of the water found in the soil is accessible for the plants, and this fraction differs in the different soils, as it depends on the water capacity of the soil, i. e. the ability of the soil to keep the water. The capacity of clay soil thus is considerably greater than that of a sandy soil. Clay soil and sandy soil both containing e. g. 14 per cent. water thus are not equally moist for the plants, as a far greater part of the water may be absorbed by the plants on the sandy soil than on the clay soil. A suitable method for the determination of the water capacity of the soil does not exist; on the whole there is no method by which the conditions of moisture of two habitats can be compared with each other.

[2]) The hydrogen ion concentration was measured electrometrically for all the soil samples, half of the samples also colorimetrically. The p_H-values stated in the tables are those electrimetrically measured.

lysis are stated in the tables, as also their number of frequency together with the number and the density of the species; besides is stated for some of the localities examined the light value measured and the result of the investigation of the transformation processes of the nitrogen in the soil. For a few localities a determination has been made of the quantities of potassium, phosphate and calcium found in the soil and soluble in distilled water saturated with carbonic acid. The result of these investigations will also be seen from the tables.

On the basis of all the material in the tables 18—26 the average frequency of the single wood ground species in each of the before mentioned 9 p_H classes has been made out, and the result will be seen from table 27, which has been elaborated in the same way as table 14. It appears from this table that *Vaccinium myrtillus, Deschampsia flexuosa, Carex pilulifera, Luzula pilosa, Convallaria majalis, Majanthemum bifolium* and *Trientalis europaea* are the species found most frequently in the most acid wood soils. These species are besides nearly the same as those described by Müller as characteristic for the raw humus soil. On the middle acid wood soil (p_H 4.5—6.0) *Melica uniflora, Milium effusum* and *Asperula odorata* have their greatest frequency, while *Hordeum europaeum Mercurialis perennis, Allium ursinum, Aegopodium podagraria, Brachypodium silvaticum, Ficaria verna, Geum urbanum, Anemone hepatica* and *Sanicula europaea* have their greatest frequency in slightly acid, neutral and alkaline soil.

In table 27 is moreover for each p_H class stated the average of the number of the species found in the localities examined as also the average of their density. As was the case with the meadows both the number of the species as their density are greatest on habitats with neutral-slightly alkaline soil (p_H 7.0—7.4), and the number of the species and their density is decreasing with the increasing hydrogen ion concentration of the soil; likewise both the number of the species as the density are lower in the very alkaline soil (p_H 7.5—7.9) than in the neutral-slightly alkaline one.

Finally it has been examined as regards the single species how the percent number of occurrences with frequency 50 and more than 50 is distributed in the 9 p_H classes. The result will ap-

pear from table 28, which has been elaborated in the same way as table 16[1]).

It is not possible to make a determination of the hydrogen ion concentration of wood soil by means of the vegetation after the method mentioned for the meadows, because the ground formations of the forests of beech-trees are too poor on species. On several of the localities examined only a single species is found — as will be seen from the tables — and it is impossible more closely to determine the hydrogen ion concentration by means of a single species; this will be easily understood when glancing at table 27.

On 44 of the localities examined investigations have been made on the course of the transformation processes of nitrogen in the soil. The results hereof as aforementioned will be found in the tables 18—26 and also in the following table 29, where the localities are arranged according to the decreasing hydrogen ion concentration of the soil. It will be seen that the nitrification is wanting or is extremely slight in the most acid soils, i. e. the raw humus soils, consequently the raw humus soil plants are for the greater part obliged to cover their consumption of nitrogen with ammonia, of which rather considerable quantities are formed in the raw humus. In several of the raw humus soils examined at least as large quantities of ammonia nitrogen are formed as of nitrate nitrogen formed in the more nitrificating soils. Thus in all the examined wood soils, even in the most acid ones ample quantities of inorganized nitrogen compounds are formed, so that wood soil plants hardly anywhere, not even on the raw humus soil may suffer from want of nitrogen. Besides it will be seen from table 29 that the greater quantities of ammonia — just as was the case with the meadow soils — are found in the most acid soils, the smallest quantities in the alkaline ones, in which the nitrification passes off most completely.

As will be seen from the preceding, the raw humus soil localities take up an exceptional position as regards the course of the transformation processes of nitrogen, as the nitrification is wanting. Regarding the other localities a closer connection be-

[1]) A table on the number of occurrences without regard to the frequency of the single species in the 9 p_H classes, i. e. corresponding to table 15, has been elaborated, but is not published here, as it does not give any essentially different idea of the distribution from that given in table 28.

Table 29. The quantity of nitrogen in the wood soils.

Locality no.	P_H	per cent. H_2O	In 1 kilo dry soil was found mg NO_3		In 1 kilo dry soil was found mg NH_4	
			at once	after one month	at once	after one month
79	3.5	40	0	0	10	51
80	3.5	38	0	0	4	107
82	3.6	45	0	0	10	60
88	3.8	25	0	0	2	38
91	3.9	20	1	1	3	12
92	3.9	28	1	1	4	10
93	4.0	15	0	0	1	10
94	4.0	29	0	0	27	82
95	4.0	33	0	0	14	70
99	4.1	38	0	190	7	212
100	4.1	25	0	0	2	30
104	4.2	51	0	13	6	105
105	4.2	40	0	2	99	150
106	4.2	22	0	0	2	40
107	4.2	26	1	2	4	31
116	4.5	21	25	382	6	16
117	4.6	26	13	385	11	57
121	4.6	26	10	412	12	16
129	4.7	22	15	188	3	2
141	5.0	20	37	209	7	9
146	5.1	23	12	95	5	5
157	5.2	23	0	191	6	7
161	5.3	19	9	240	5	30
167	5.4	32	5	242	20	69
175	5.5	22	3	202	6	40
176	5.5	28	0	117	5	12
181	5.6	21	11	89	8	17
194	6.0	16	21	114	5	3
195	6.0	18	23	100	5	3
196	6.0	26	8	215	5	2
199	6.1	30	24	89	5	3
204	6.2	31	0	269	9	12
208	6.3	19	14	112	1	2
219	6.5	30	70	222	3	3
223	6.6	21	6	185	6	4
226	6.7	28	40	310	3	3
230	6.8	25	20	111	1	2
246	7.4	24	15	122	2	1
251	7.5	35	19	109	1	1
256	7.6	32	12	152	1	1
257	7.6	28	23	152	0	0
258	7.6	26	20	92	0	0
263	7.8	28	23	240	0	1
264	7.8	26	31	70	4	2
265	7.8	25	10	96	0	0

tween the composition of the vegetation and the course of the transformation processes of nitrogen cannot be pointed out.

Finally as mentioned above a determination of the quantities of potassium, phosphate and calcium soluble in distilled water saturated with carbonic acid has been made in soil samples from 12 of the localities examined. These analysis have been grouped in table 30 according to the hydrogen ion concentration of the soil samples.

Table 30.

Locality no.	82	104	121	161	175	194	199	208	223	246	251	257
p_H	3.6	4.2	4.6	5.3	5.5	6.0	6.1	6.3	6.6	7.4	7.5	7.6
K (mg in 1 kilo dry soil)	25	28	24	17	15	33	46	24	30	114	83	12
PO_4	0.3	0.2	2.0	2.0	2.0	3.0	8.0	12.0	4.0	4.0	0.2	16.0
Ca	27	25	42	40	45	79	125	207	102	1275	2311	1747

As will be seen, no fixed relation is found between the quantities of potassium and phosphate and the hydrogen ion concentration; on the other hand it appears that the more acid the soils are, the less calcium will on an average be found in the soils. The results of the analysis besides do not imply any closer relation between the composition of the vegetation and the contents of the soil of mineral plant nutrients soluble in water saturated with carbonic acid, calcium however excepted.

Finally I want to mention some investigations of beech-tree forests where the ground vegetation is wanting. Great tracts of Grib Forest. especially the middle parts round Grib Sea and Maglemose bear old beech-tree forests, the soil of which in most places is devoid of vegetation. The light which reaches the soil amounts to 3—5 per cent. of the free daylight; this quantity of light cannot be said to be so small as not to allow the existence of a ground vegetation. In these areas the soil is a very loose and soft raw humus, the hydrogen ion concentration of which measured in soil samples from 10 different localities was found to be from 3.7—3.8, expressed in p_H. No nitrification takes place in these soils, but on the other hand a very active formation of ammonia; the 10 soil samples examined contained after having stood for one month in the Laboratory no nitrate, but

ample ammonia (from 30—60 mg calculated as NH_4 per one kilo dry soil). The reason of the wood soil being devoid of vegetation is presumably due to the high hydrogen ion concentration of the soil in connection with want of light, as the high hydrogen ion concentration does not allow the species standing more shade among the mould plants to grow here, while want of sufficient light in general will keep away the raw humus plants which commonly demand more light. Where the forest in single spots is lighter or where the forest adjoins cut areas, meadows and the like, a ground vegetation of raw humus plants will be found, especially formed by *Deschampsia flexuosa*, *Vaccinium myrtillus* and moss species.

Alteration of the Hydrogen ion Concentration of the Soil when the Forest is cut.

In the following I shall briefly mention some investigations made on the alteration in the abietic raw humus when the forest is cut. All the investigations have been made in Grib Forest, where the soil below the older spruce-forest always is covered by a layer of raw humus about 5—10 cm thick. As a rule the soil is without vegetation, which of course principally is due to want of light; in some cases it may, however, where the plantation is not so dense be covered by an extremely luxuriant moss carpet, for the greater part consisting of *Scleropodium purum*, *Hylocomium splendens* and *H. Schreberi*, as is the case in locality no. 269 (table 31). As will be seen from table 31 [1]), the raw humus is very acid (p_H 3.4—3.6) under the red pine plantations, and no nitrification takes place in it, but on the other hand a very considerable formation of ammonia.

When the spruce-forest is cut, a dense growth of *Senecio silvaticus* (locality nos. 272—278, table 31, see also fig. 3) appears the very first summer. At the same time, however, an alteration takes place in the raw humus, this becoming loose and crumbling, and the hydrogen ion concentration — as will be seen from the table — has decreased very much from p_H = 3.5 to about 5.0

[1]) The p_H values indicated in table 31 are electrometrically measured; this also holds good of the p_H values in table 32 and 33.

and an active formation of nitrate[1]) begins. In a single soil sample (from locality no. 275) so much nitrate was formed in the course of one month that, calculated as NO_3 it amounts to 1 g in one kilo dry soil. In spite of the very great quantities of nitrate

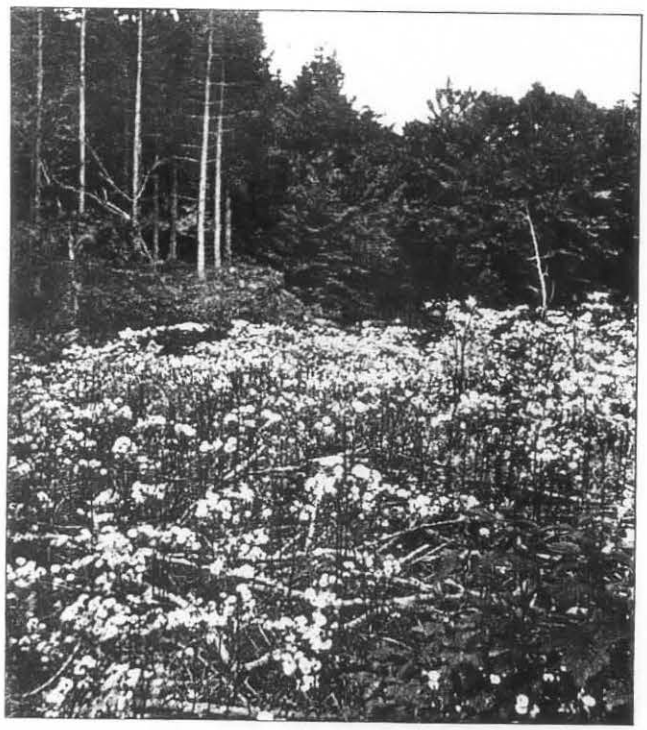


Fig. 3. Locality no. 273. Grib Forest. *Senecio silvaticus* (with ripe fruits) on the soil of a cut spruce-forest. To the right in the front *Rubus idaeus* is seen. (Phot. $^{20}/_{8}$ 1917).

formed in these soils the nitrification of the nitrogen must be said to be incomplete, as only about half of the ammonia nitrogen is transformed into nitrate. Furthermore it will appear that as far as the few analysis allow a certain conclusion, considerably greater quantities of easily soluble mineral plant nutrients are found in the cut soil than in the soil below the spruce-forest. It is hardly possible to say anything certain of the reason of the quick de-

[1]) The Swedish investigator Hesselman has likewise substantiated that an active nitrification takes place in the soil after cutting of pine forest. (Hesselmann 1917).

Table 31. Analysis of the soil of cut spruce-forest and its vegetation (Grib Forest).

	Dense spruce-forest					1—2 years after the cutting							3—4 years after the cutting					4—5 years after the cutting	
p_H of the soil sample	3.4	3.5	3.6	3.6	3.6	5.6	5.2	5.0	5.1	4.8	4.9	4.9	4.4	4.3	4.7	4.4	4.5	3.8	3.8
Locality no.	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285
Deschampsia flexuosa	»	»	»	»	»	»	»	20	»	30	»	10	»	»	»	20	**100**	**100**	**100**
Rubus idaeus	»	»	»	»	»	»	10	»	»	»	»	**50**	**100**	40	20	**100**	»	»	»
Chamaenerium angustifolium	»	»	»	»	»	»	30	20	10	»	»	»	30	**100**	**100**	**80**	**100**	10	»
Senecio silvaticus	»	»	»	»	»	**100**	**100**	**100**	**100**	**100**	**100**	**100**	10	»	»	»	10	»	»
Juncus conglomeratus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	10
Luzula pilosa	»	»	»	»	»	»	»	»	»	10	10	30	»	»	»	»	»	»	»
Carex pilulifera	»	»	»	»	»	»	»	10	»	»	»	40	»	»	»	10	10	»	»
Rumex acetosella	»	»	»	»	»	»	»	30	»	»	10	»	»	»	»	»	20	10	»
Calluna vulgaris	»	»	»	»	»	»	»	»	»	»	»	»	10	»	»	20	»	»	20
Vaccinium myrtillus	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	30
Galium harcynicum	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	»	40
In the soil sample: per cent H_2O	70	53	69	51	56	51	54	50	69	65	57	29	»	66	22	»	»	50	43
In the soil sample: NO_3 at once	0	0	0	0	0	42	9	143	30	210	56	42	»	105	**2**	»	»	0	0
In the soil sample: — after one month	0	0	0	0	0	157	552	778	1290	882	420	366	»	192	**51**	»	»	0	0
In the soil sample: NH_4 at once	8	30	10	4	15	10	104	98	105	100	117	37	»	4	5	»	»	4	10
In the soil sample: — after one month	115	147	139	112	232	10	214	193	355	227	189	56	»	15	30	»	»	42	63
In the soil sample: K	»	18	»	»	21	»	42	»	»	»	»	39	»	»	»	»	»	»	»
In the soil sample: PO_4	»	0.1	»	»	0.1	»	0.5	»	»	»	»	0.4	»	»	»	»	»	»	»
In the soil sample: Ca	»	25	»	»	23	»	153	»	»	»	»	113	»	»	»	»	»	»	»

composition of the raw humus after the cutting; perhaps the light plays a part.

As will be seen from table 31, another alteration of the soil takes place during the following years (3—4 years after the cutting), where *Chamaenerium angustifolium* and *Rubus idaeus* are the dominant species, as the hydrogen ion concentration gradually increases while the nitrification at the same time decreases. At this time *Deschampsia flexuosa* as a rule begins to immigrate. 4—5 years after the cutting the hydrogen ion concentration of the soil has nearly reached the same value as in the soil of the spruce-forest. The nitrification has by now ceased completely and the raw humus layer is highly reduced. At that time *Deschampsia flexuosa* is as a rule the dominant species. That the alteration of the soil is not due to the immigration of this species appears from the fact, that the soil from uncovered spots between the tufts of this grass species does not behave otherwise than the soil below the tufts.

The course of development shown in the table has of course not been followed directly in a single locality, but is based on a combination of a number of localities. However, the localities entered in the table as no. 273 and no. 284 are in reality the same localities examined for the first time in 1917 (no. 273), for the second time in the summer 1920 (no. 284). The spruce-forest on this locality was cut in the autumn 1916.

When the beech-forest is cut a similar alteration probably takes place with the hydrogen ion concentration of the soil as described above with regard to the spruce-forest. The results stated in table 32 of analysis made in 1919 on a locality in Ermelunden where an area covered with wood some years before had been cut seem to imply this. In the beech-forest abutting on the cut area the ground vegetation consisted in *Anemone nemorosa* and *Oxalis acetosella*, and the hydrogen ion concentration of the soil expressed in p_H was found to be 5.2 (locality no. 286). At the bound of the beech-forest and the cut area, where *Mercurialis perennis* was the dominant species, the hydrogen ion concentration of the soil expressed in p_H had a value of 6.0 (locality no. 287) and on the cut area, where the nettle was dominanting, it had a value of 6.6 (locality no. 288). Thus the hydrogen ion concentration was lower in the soil on the cut area than in the soil in the surrounding forest.

Table 32.

	Dense growth	Limit between the growth and the cut area	Cut area
p_H of the sample	5.2	6.0	6.6
Locality no.	286	287	288
Anemone nemorosa	100	100	»
Oxalis acetosella	100	90	»
Mercurialis perennis	»	100	»
Geranium Robertianum . . .	»	50	50
Geum urbanum	»	60	40
Urtica dioeca	»	20	100
Milium effusum	20	»	»
Rumex nemorosus	»	»	10
Ficaria verna	»	30	»
Rubus idaeus	»	»	40
Scrophularia nodosa	»	»	30
Cirsium arvense	»	»	20

Some formations on sunny mineral soil and their habitats.

On sunny mineral soil I have made analysis of formations and habitats in ten different localities. The results of the analysis will be found in table 33, arranged according to the decreasing hydrogen ion concentration of the soil. The three first mentioned localities are from heaths in Jutland. The formation in the first mentioned locality (no. 289), an old west Jutich heath covered with a thick layer of dry peat (raw humus) and underlying bleached sand and hard pan, is that poorest on species and is found on the most acid soil (p_H = 3.6). The two following localities (nos. 290 and 291) are hilly heaths near Skørping. The soil in these heaths is of a more mouldy nature and below the heather is a layer of bleached sand which is only slightly developed, while the hard pan is completely wanting. As will be seen from the table the soil in these localities is somewhat less acid and the number of the species and their density are somewhat greater than is the case as regards the before mentioned west Jutich heath. (In locality no. 291 both the number of the species and their density are considerably greater than in

Table 33. Analysis of formations and habitats from ten localiteties with sunny mineral soils.

Locality no. 289 is situated in a heath near Ulfborg in the western part of Jutland, nos. 290 and 291 in heath east of Frær Parker near Skørping (the heather on locality no. 291 burned in 1915; the investigation took place in 1919), no. 292 on the Eremitageslette near Hjortekær, no. 293 in a plane in Jægersborg deer-park, no. 294 in Silstrup hills near Thisted, no. 295 in the Have valley near Skørping, no. 296 on a slope near Blaakilde in the Buderup valley (Skørping), no. 297 in an old sea-bluff at Klitgaard near Nibe and no. 298 in an open plane in Allindelille Fredskov. The soil in the four last mentioned localities essentially consists of calcium carbonate (chalk).

p_H of the soil sample	3.6	3.9	4.2	4.7	5.2	6.2	7.4	7.5	7.7	7.7
Locality no.	289	290	291	292	293	294	295	296	297	298
Calluna vulgaris	100	100	60	60	»	»	»	»	»	»
Empetrum nigrum	10	80	»	»	»	»	»	»	»	»
Vaccinium vitis idaea	»	70	70	»	»	»	»	»	»	»
Deschampsia flexuosa	»	10	50	»	»	»	»	»	»	»
Vaccinium myrtillus	»	10	80	»	»	»	»	»	»	»
Arnica montana	»	»	90	»	»	»	»	»	»	»
Festuca ovina	»	»	»	100	100	»	80	30	40	»
Agrostis tenuis	»	»	»	90	100	»	»	»	»	»
Sieglingia decumbens	»	»	»	60	»	»	»	»	»	»
Veronica chamaedrys	»	»	»	50	20	»	»	10	»	10
Achillea millefolium	»	»	»	90	100	100	20	60	60	80
Avena pratensis	»	»	»	»	60	»	»	»	»	»
Anthoxanthum odoratum	»	»	»	40	100	»	»	»	»	»
Galium verum	»	»	»	30	100	80	»	»	30	80
Dactylis glomerata	»	»	»	»	»	100	»	100	100	30
Festuca rubra	»	»	»	»	»	100	50	100	100	100
Agrostis alba	»	»	»	»	»	60	»	»	»	»
Rumex acetosa	»	»	»	»	20	50	»	»	50	»
Hypericum perforatum	»	»	»	»	»	100	30	»	10	20
Plantago lanceolata	»	»	»	»	40	80	»	»	20	40
Origanum vulgare	»	»	»	»	»	100	»	»	10	40
Campanula glomerata	»	»	»	»	»	100	»	60	50	»
Carlina vulgaris	»	»	»	»	»	50	40	30	»	»
Carex glauca	»	»	»	»	»	20	80	80	100	100
Festuca elatior f. pseudololiacea	»	»	»	»	»	»	60	100	100	»
Avena pratensis	»	»	»	»	»	»	80	60	»	»
Koeleria pyramidata	»	»	»	»	»	»	100	»	100	»
Poterium sanguisorba	»	»	»	»	»	»	100	50	20	»
Medicago lupulina	»	»	»	»	»	»	90	50	50	50
Brunella vulgaris	»	»	»	»	»	»	90	100	20	30
Briza media	»	»	»	»	»	»	30	60	100	100
Linum catharticum	»	»	»	»	»	»	»	100	30	10
Plantago media	»	»	»	»	»	»	40	50	80	»
Calamintha acinos	»	»	»	»	»	»	40	100	100	»
Gentiana uliginosa	»	»	»	»	»	»	30	50	»	»
Galium mollugo	»	»	»	»	»	»	10	100	»	»
Valeriana officinalis	»	»	»	»	»	»	»	60	»	»
Poa pratensis	»	»	»	»	10	»	»	»	100	»
Primula veris	»	»	»	»	»	»	»	40	60	»
Galium boreale	»	»	»	»	»	»	»	»	50	20
Cirsium acaule	»	»	»	»	»	»	30	30	80	90
Brachypodium silvaticum	»	»	»	»	»	»	»	»	»	90
Anemone hepatica	»	»	»	»	»	»	»	»	»	100
Polygala vulgare	»	»	»	»	»	»	»	»	»	80
Fragaria vesca	»	»	»	»	»	»	»	40	10	70
Ononis repens	»	»	»	»	»	»	40	20	40	100
Lotus corniculatus	»	»	»	»	»	»	40	30	30	50
Pimpinella magna	»	»	»	»	»	»	»	»	»	80
Selinum carvifolium	»	»	»	»	»	»	»	20	»	100
Campanula rotundifolia	»	»	»	»	30	»	»	»	30	50
Valeriana dioeca	»	»	»	»	»	»	»	»	»	100
Scabiosa columbaria	»	»	»	»	»	»	»	»	»	80
Centaurea jacea	»	»	»	»	»	»	»	20	20	60
Leontodon hispidus	»	»	»	»	»	»	»	»	»	80
Botrychium lunaria	»	»	»	»	»	»	»	10	»	»
Luzula campestris	»	»	»	»	20	»	»	»	»	»
Carex panicea	»	»	10	»	»	»	»	»	»	»

(To continue p. 96—97.)

Table 33 continuation.

pH of the soil sample	3.6	3.9	4.2	4.7	5.2	6.2	7.4	7.5	7.7	7.7
Locality no.	289	290	291	292	293	294	295	296	297	298
Carex pilulifera	»	10	10	»	»	»	»	»	»	»
— caryophyllea	»	»	»	»	20	»	»	»	»	»
— digitata	»	»	»	»	»	»	40	10	»	»
— hirta	»	»	»	»	10	»	»	»	»	»
Poa compressa	»	»	»	»	»	»	20	»	»	»
Molinia coerulea	»	»	10	»	»	»	»	»	»	»
Holcus lanatus	»	»	»	»	10	40	»	»	»	»
Deschampsia caespitosa	»	»	»	»	»	»	»	20	»	»
Avena pubescens	»	»	»	»	»	»	»	»	»	10
Cynosurus cristatus	»	»	»	10	40	»	»	»	»	»
Phleum pratense	»	»	»	»	»	30	»	»	»	»
Majanthemum bifolium	»	»	40	»	»	»	»	»	»	»
Rumex acetosella	»	»	»	20	»	»	»	»	»	»
Melandrium album	»	»	»	»	»	»	»	»	20	»
Ranunculus acer	»	»	»	»	»	»	»	»	40	»
— bulbosus	»	»	»	20	30	»	»	»	»	»
Anemone nemorosa	»	»	»	»	»	»	»	»	»	20
Arabidopsis Thaliana	»	»	»	»	»	10	»	»	»	»
Mercurialis perennis	»	»	»	»	»	»	»	»	»	10
Helianthemum nummularium	»	»	»	»	»	»	»	»	»	10
Polygala amarellum	»	»	»	»	»	»	20	40	»	»
Parnassia palustris	»	»	»	»	»	»	»	»	»	30
Potentilla erecta	»	»	30	30	»	»	»	»	»	»
Geum rivale	»	»	»	»	»	»	»	»	»	10
Rubus saxatilis	»	»	»	»	»	»	»	»	»	40
Agrimonia eupatoria	»	»	»	»	»	10	»	»	»	»
Anthyllis vulneraria	»	»	»	»	»	»	20	30	»	10
Vicia cracca	»	»	»	»	»	»	»	10	30	40
Lathyrus pratensis	»	»	»	»	»	20	»	»	»	10
Trifolium repens	»	»	»	»	30	»	»	»	»	»

pH of the soil sample	3.6	3.9	4.2	4.7	5.2	6.2	7.4	7.5	7.7	7.7
Locality no.	289	290	291	292	293	294	295	296	297	298
Trifolium medium	»	»	»	»	»	»	30	10	»	»
Genista anglica	10	»	20	»	»	»	»	»	»	»
Pimpinella saxifraga	»	»	»	»	»	»	40	»	40	10
Heracleum sphondylium	»	»	»	»	»	»	»	20	»	10
Daucus carota	»	»	»	»	»	40	30	»	»	»
Trientalis europaea	»	10	»	»	»	»	»	»	»	»
Linaria minor	»	»	»	»	»	»	»	40	»	»
Alectorolophus crista galli	»	»	»	»	»	»	»	»	»	30
Thymus chamaedrys	»	»	»	»	»	»	»	»	»	40
Valeriana excelsa	»	»	»	»	»	»	»	»	»	20
Succisa pratensis	»	»	»	»	»	»	»	30	30	20
Centaurea scabiosa	»	»	»	»	»	»	»	»	40	»
Tussilago farfarus	»	»	»	»	»	20	»	20	»	»
Chrysanthemum leucanthemum	»	»	»	»	»	»	»	»	40	»
Cineraria integrifolia	»	»	»	»	»	»	»	»	20	»
Senecio Jacobaea	»	»	»	»	»	20	»	»	»	»
Hieracium pilosella	»	»	10	10	20	»	20	10	»	»
Number of species	3	7	12	13	19	20	28	39	37	44
Density of species	1.2	2.9	4.8	6.1	8.6	11.3	13.0	18.0	18.5	21.6
In the soil sample: per cent H_2O	12	16	14	20	21	»	15	13	12	17
In the soil sample: NO_3 at once	0	0	0	0	0	»	30	8	30	0
In the soil sample: — after one month	0	0	0	0	14	»	41	10	35	0
In the soil sample: NH_4 at once	0	0	0	3	4	»	2	4	0	1
In the soil sample: — after one month	0	1	2	10	12	»	2	3	2	2
In the soil sample: K	17	20	»	»	»	»	27	26	11	21
In the soil sample: PO_4	0.1	0	»	»	»	»	0.2	0.3	0.2	0.2
In the soil sample: Ca	20	16	»	»	»	»	1911	2035	2277	2021

locality no 290, but this is partly due to the fact that the vegetation after heath-fire four or five years ago has not yet come into equilibrium with the surroundings.

No nitrification takes place in the three heath soils examined and it will be seen, that the formation of ammonia is extremely small. Likewise very small quantities of phosphate and potassium are found here. The heath soil therefore is very poor on plant nutrients, what besides is a wellknown matter.

The formations following the heath formations in the table show parallel with the decreasing hydrogen ion concentration of the soil increasing number of the species and their density that culminate in the four mentioned formations which all are found on calcareous soil.

As will be seen, comparatively small quantities of nitrate and ammonia are formed in the soil on open mineral soil, far less than in the wood-soils and the meadow-soils which, I suppose, is due to the poorness of the sunny mineral soils on organic moulding substances. In the soil from the last mentioned locality is a sunny calcareous plane in Allindelille Fredskov which is very poor on mould, in which on the whole no nitrate has been shown. In this plane as also in other similar ones in Allindelille and Kastrup Forest I have repeatedly selected soil samples, but I have never been able to substantiate even the slightest nitrification. Only very small quantities of ammonia and phosphate are found. These soils which almost exclusively consist of calcium carbonate (chalk) are thus extremely poor on plant nutrients and in this respect resemble the heath soil very much. They bear a vegetation very rich on species as also the density of the species is very great. Owing to the poorness on plant nutrients [1]) the single plants are not highly developed and the annual production of matter of the plants is only inconsiderable. Despite the poorness on plant nutrients the vegetation as regards the species found, their number and density, is very different from those of the very acid soils that also are poor on nutrients. This does not imply that the different contents of plant nutrients of the soils

[1]) The said calcareous planes in Allindelille Forest and Kastrup Forest have surely never born forests, nor can they be expected to do so, as the few wood-trees which are sowing themselves always are decaying and finally fade away. The reason hereof is without doubt the great poorness of the soil on plant nutrients.

plays a greater part as a plant distributing factor than the hydrogen ion concentration. According to some authors the contents of plant nutrients of the soil is said to vary regularly with the variations of the hydrogen ion concentration the most acid soils being poorest on plant nutrients, the neutral and basic soils being the richest. As will be seen from the preceding, this rule is not without exceptions.

Recapitulation of the results of the investigations.

It has been substantiated at the investigations treated in this section, that the hydrogen ion concentration in natural Danish soils lies between the limits 3.4 and 8.0 expressed in p_H- and that the composition of the vegetation depends on the hydrogen ion concentration of the soil, as the single species only are found on soil the hydrogen ion concentration of which lies within a certain range of hydrogen ion concentration characteristic for each single species. Within this range is another narrower range in which the species has its greatest average frequency. As regards the meadows a conclusion may be drawn from the composition of the vegetation to the hydrogen ion concentration of the soil. Furthermore it has appeared that both the number of the species as their density on an average are greatest on soil the hydrogen ion concontration of which lies near the neutral point. With the increasing hydrogen ion concentration of the soil both the number of the species as their density as a rule decrease. On very alkaline soil the number of the species and their density are on an average somewhat lower than in the neutral soil. This soil, therefore, seems to be the most favourable for the growth of most species, while the very acid soil seems to be the most unfavourable.

Thus the hydrogen ion concentration of the soil plays an essential part as a plant distributing factor. As mentioned in the introduction, it may however be a question of both direct and indirect effects hereof. As regards the direct ones the stress has — as mentioned above — been laid on three different effects, i. e. 1) the influence of the hydrogen ion concentration on the contents of mineral plant nutrients of the soil, 2) its influence on the course of the transformation processes of nitrogen, especially the nitrification, as this is said to be more active in neutral

and alkaline soils, weak or wanting in the very acid ones, 3) its influence on the solubility of the aluminum compounds of the soil.

As mentioned above the very acid soils are generally considered as those poorest on mineral plant nutrients, while the neutral and alkaline soils are considered to be the richest hereon. It will appear from the investigations that this as a general rule is not correct, for although the most acid soils have shown to be poor on mineral plant nutrients especially on phosphate, the very alkaline soils, i. e. the soils essentially consisting of calcium carbonate, may be extremely poor on these nutrients. If it was not the different hydrogen ion concentration of the soils examined but their different contents of plant nutrients, which was the reason of their different vegetation, the acid soil poor on nutrients must resemble the alkaline soils poor on nutrients with regard to their vegetation, but this is absolutely not the case.

It will furthermore appear from the investigations that there does not exist in general any closer connection between the intensity of the nitrification and the hydrogen ion concentration of the soil, and that considerable quantities of nitrate may even be formed in very acid soils. In the acid soils more ammonia nitrogen will as a rule be found than in the neutral and alkaline ones, in which the whole quantity of nitrogen liberated quickly is passed into nitrate. Only in the most acid soils, i. e. in the high moor peat, in the heath soils and in most raw humus soils the nitrification does not take place. In the two first mentioned soils the nitrogen is virtually not transformed, as only minimal amounts of ammonia are formed. In the high moor peat and in the heath soil the nitrogen — as besides pointed out by Müller (1918) — is found in organic bound condition and therefore must be considered as being nearly inaccessible for the higher plants. It is otherwise with the raw humus soils, for although as a rule no nitrification takes place in these soils a formation of ammonia takes places, a formation which even in many cases is considerable. With regard to the raw humus plants it is, therefore, possible, that these plants essentially owe their appearance on the raw humus to the fact that these plants either demand ammonia compounds or at any rate better than other plants are able to use these compounds and that this special ability of the raw humus plants to a higher degree than their sensibility to the hydrogen ion concentration of the soil is the

reason of their occurrence on the raw humus. However, it will appear from the experiments which will be mentioned in the following section, that the nitrate nitrogen and ammonia nitrogen are of the same value as a source of nitrogen both for the alkaline soil plants as for the acid soil plants (including raw humus plants).

Apart from the above mentioned very acid not nitrificating soils it has not been possible with regard to the other soils to show any connection between the intensity of the nitrification and the plant distribution. Thus the investigations made suggest that either it must be the different hydrogen ion concentration of the soils or the degree of solubility dependent on the hydrogen ion concentration of the aluminum compounds of the soil that is a reason of the differences of the vegetation that have been found, in case there are no other factors which vary regularly with the hydrogen ion concentration of the soil than those mentioned above.

It will appear from the culture experiments described in the following section than an essential significance for the plant distribution directly must be attributed to the hydrogen ion concentration. It will also appear that the plants found on acid and alkaline soil respectively generally do not react differently to aluminum compounds in solution.

B. CULTURE EXPERIMENTS.

The growth of the plants in growing media of different hydrogen ion concentrations.

In the literature only few investigations have been published on the growth of the plants in growing media of different hydrogen ion concentrations. A number of older investigations (Heald 1896, Kahlenberg and True 1896, Hartwell and Pember 1907, Breazeale and Le Clerc 1912, Dachnowski 1914, Miyake 1914) on the growth of the plants in liquids containing different quantities of acid and base are only of small interest, as no regard is paid to the hydrogen ion concentration and its possible alterations during the experiments, that often were made with pure acid or basic solutions without plant nutrients. Of late years Hoagland (1917) has by means of water culture experiments examined the growth of barley in liquids of different hydrogen ion concentration[1]). At the experiments which were made with young plants and which only covered a period of a fortnight, it appeared that the plants were growing equally and very well in nutrient liquids, the p_H value of which was 5, 6 and 7, while the plants could not stand nutrient liquids with a p_H value of 3.5 and lower values, nor was it possible to make the plants develop in liquids the p_H value of which was 8.4.

Investigations have also been made by Joffe (1920 II) who cultivated alfalfa in soil the hydrogen ion concentration of which was varied; the different hydrogen ion concentrations were artificially brought about by means of sulphuric acid and calcium carbonate. He found that the growth of alfalfa was decreasing with the increasing hydrogen ion concentration of the soil. In soils with a p_H value lower than 4.8 the growth was highly checked.

What is of special interest, however, in connection with the investigations mentioned in this treatise on the significance of the hydrogen ion concentration of the soil as a plant distributing factor is the question, whether the different species reach

[1]) In order to avoid precipitations in the basic nutrient liquids Hoagland omitted calcium, magnesium and iron of all the nutrient liquids on the ground that the plants for a shorter experimental period might be able to procure sufficient quantities of these substances from the seeds.

their most vigorous growth at hydrogen ion concentrations characteristic of the different species. From investigations made by Maxwell (1898) on the Sandwich Islands it seems to appear that different culture plants unequally stand high acid concentrations. Maxwell namely found that the ability of the different culture plants to grow in soil watered with citric acid in solution was not the same. Thus alfalfa, barley, wheat, white mustard and rape succumbed if the soil, in which they grew, was watered with citric acid of 0,1 per cent, while maize and especially pearl millet (sorghum) stood this treatment very well. The two latter species also appeared to be the only ones thriving in the very acid soils, which according to Maxwell are found in many places in the Sandwich Islands.

Finally a paper has been published by Salter and Mc Ilvaine (1920) on the growth of some culture plants in nutrient liquids of different hydrogen ion concentrations. The two authors came to the conclusion that maize reached its best growth in nutrient liquids, the p_H value of which was 5, while wheat, soyabeans and alfalfa were thriving best in nutrient liquids, the p_H value of which was 6. Thus maize seems to favour a higher hydrogen ion concentration than the three other species.

The object of my experiments was to examine, whether the species especially found on very acid soil (acid soil plants) are thriving best in growing media of higher hydrogen ion concentration than the species found especially in slightly acid, neutral, and alkaline soil (alkaline soil plants). For these experiments I therefore partly selected acid soil plants, partly alkaline soil plants, but of course only such species as are growing comparatively quickly as the experiments could not cover more than one period of growth.

Besides Danish indigenes a single culture plant, i. e. barley *(Hordeum distichum)* was included in the experiments, which must be considered as an alkaline soil plant, as it only reaches a satisfactory development in arable soil giving an alkaline or a neutral reaction.

Experiments on the growth of different species in natural soil of different hydrogen ion concentration. During the summer 1918 a series of experiments was made. The alkaline soil plants *Tussilago farfarus* and *Poterium sanguisorba* and the acid soil plants *Senecio silvaticus* and *Deschampsia*

flexuosa were cultivated in 7 different soils, the hydrogen ion concentrations of which were known and varied over the p_H range 3.6—7.7.

The soils originated with 7 of the localities mentioned in the previous section, from which very large soil samples had been carried home. A part of each of these soil samples was used for the soil analysis, the results of which will be found in the tables 18 (loc. no. 82), 21 (loc. no. 167), 24 (loc. no. 226), 26 (loc. no. 257), 31 (loc. no. 273) and 33 (loc. no. 292 and 298). The results of the analysis are also stated in table 34. For convenience the soils are here designated with the letters (a—g) stated at the top of the table. Below the letters is stated the number of the locality from which the soil samples originated.

The soils were put in flower-pots each holding about 2 litres of soil. The pots were then placed in the open air and were daily watered with distilled water. The plants to be experimented on were sown in the flower-pots on the 23rd of April. *Tussilago* however not until the 16th of May[1]). Each of the 4 species were sown severally in the 7 different soils, thus I had 4 series of experiments, one for each species, and as each series was doubled, the total number of flower-pots thus was 56. As soon as the plants had developed, a thinning was made, care being taken that the number of remaining plants of each species was the same in all the flower-pots.

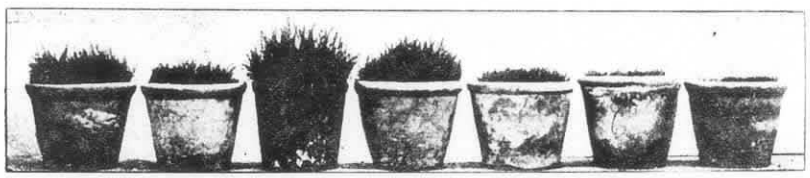
The plants of *Deschampsia flexuosa* were growing very badly in soil e, f and g (see fig. 4), and in these soils they were highly chlorotic from the very beginning. In the 4 other soils the plants had a pure green colour, in the two most acid soils even a deep dark green colour[2]).

Senecio silvaticus and *Deschampsia flexuosa* grew extremely badly in nearly neutral and alkaline soils (e, f and g, see fig. 5). In soil g, calcareous soil poor on mould from Allindelille Fred-

[1]) The material of seed sown was as regards *Deschampsia flexuosa* and *Senecio silvaticus* gathered the previous year in Grib Forest, as regards *Poterium sanguisorba* near Skørping, also the previous year, and as regards *Tussilago* it was gathered the same spring in Vangede. The fruits of *Tussilago* are ripe in the first half of May; then they can germinate but already at the end of May they loose for always the power of germination.

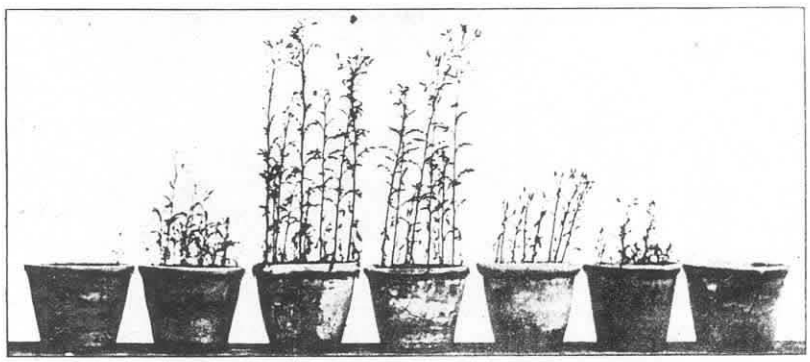
[2]) In soil b the growth of the plants was — as will be seen from fig. 4 — poorer than in soil a and c. This without doubt was due to the fact that soil b is much poorer on accessible nitrogen compounds than the other two soils.

Fig. 4—7 show the growth of 4 different species in 7 soils with different hydrogen ion concentrations. The flower-pots with the most acid soils are standing to the left, those with the alkaline soils to the right.



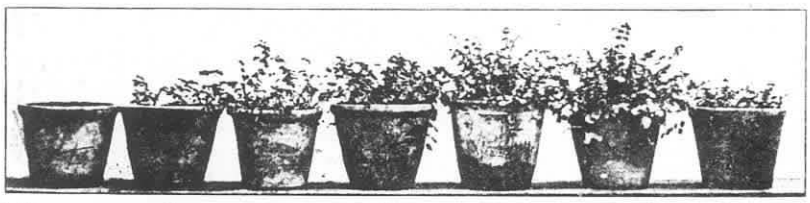
Soil	a	b	c	d	e	f	g
p_H	3.6	4.7	5.2	5.4	6.7	7.6	7.7

Fig. 4. *Deschampsia flexuosa*. Phot. $^{15}/_{8}$ 1918.



Soil	a	b	c	d	e	f	g
p_H	3.6	4.7	5.2	5.4	6.7	7.6	7.7

Fig. 5. *Senecio silvaticus*. Phot. $^{20}/_{7}$ 1918.



Soil	a	b	c	d	e	f	g
p_H	3.6	4.7	5.2	5.4	6.7	7.6	7.7

Fig. 6. *Poterium sanguisorba*. Phot. $^{15}/_{8}$ 1918.

Soil	a	b	c	d	e	f	g
p_H	3.6	4.7	5.2	5.4	6.7	7.6	7.7

Fig. 7. *Tussilago farfarus*. Phot. $^{16}/_{9}$ 1918.

skov, the plants succumbed even quite after having developed only two yellow cotyledons. In the soils c and d *Senecio silvaticus* reached its best growth; its colour was here pure green. In the most acid soil (a) most of the plants gradually died. *Senecio silvaticus* thus cannot stand as acid soil as *Deschampsia flexuosa*.

Tussilago farfarus and *Poterium sanguisorba* grew best in basic and nearly neutral soils (see fig. 6 and 7), and the growth decreased proportionally with the increasing hydrogen ion concentration of the soil. The colour of the plant was in all cases normally green, in the most acid soils, however, somewhat darker than in the other soils[1]).

As regards *Senecio* the experiments were finished on the 30th of July, as regards *Deschampsia* and *Poterium* on the 15th of August, and as regards *Tussilago* on the 16th of September. The plants were then weighed, first in fresh condition, afterwards dried. The results will be seen from table 34. Each of the numbers stated off the names of the species is the weight of the plants developed in a single flower-pot (average of the plants of two interdependent flower-pots).

It will appear from the results of the experiments that the plants pre-eminently found on very acid soil on an average are thriving best in very acid soils, those preferentially found on neutral-alkaline soils in the neutral-alkaline soils. It is a matter of course that the growth does not vary regularly with the hydrogen ion concentration of the soil, nor was this to be expected, as the soils in question also differed with regard to other factors than the hydrogen ion concentration, thus e. g. as regards the nitrification energy. The growth, however, seems more dependent on the hydrogen ion concentration than on the nitrification energy. *Senecio silvaticus*, which according to Hesselman (1917) is a nitrate plant, thrives best, it is true, in the soil in which the greatest quantity of nitrate is found, viz. soil c, but as will be seen its growth in the rather acid soil d is considerably better

[1]) As will be seen from fig. 6 the growth of *Poterium* was smaller than in soil f, although the hydrogen ion concentration of these two soils was nearly the same. This must be supposed to be due to poorness of soil g on plant nutrients, especially on nitrogen. When no difference was found with regard to *Tussilago* in soil f and g, it may be due to this plant not needing as much nitrogen as *Poterium*.

Table 34.

The growth of 4 species in 7 soils with different hydrogen ion concentrations.

Soil		a	b	c	d	e	f	g
The soils originate with locality number		82	292	273	167	226	257	298
Analysis of the soil	Pu	3.6	4.7	5.2	5.4	6.7	7.6	7.7
	NO_3 at the drawing of samples	0	0	9	5	40	23	0
	NO_3 after one month	0	0	552	242	310	152	0
	NH_4 at the drawing of samples	10	3	104	20	3	0	1
	NH_4 after one moth	60	10	214	69	3	0	2
	K	25	»	42	»	»	12	21
	PO_4	0.3	»	0.5	»	»	16	0.2
	Ca	27	»	153	»	»	1747	2021
Deschampsia flexuosa. Weight (g), fresh.		37.4	23.2	**68.3**	60.2	15.8	8.3	5.4
— — . — , dry		6.5	4.1	**12.6**	10.0	2.8	1.5	1.0
Senecio silvaticus. Weight (g), fresh		0.3	8.5	**29.0**	14.5	5.3	5.2	0
— — . — , dry		0.1	1.2	**4.8**	2.4	0.9	0.8	0
Poterium sanguisorba. Weight (g), fresh.		0	2.0	9.1	14.3	25.8	**27.0**	14.1
— — . — , dry		0	0.4	1.9	3.0	5.5	**5.5**	3.5
Tussilago farfarus. Weight (g), fresh		2.5	12.0	22.1	39.8	46.4	**50.2**	50.0
— — . — , dry		0.3	1.9	3.4	6.0	7.1	**7.2**	7.0

than in the less acid soil e, though a more active nitrification takes place in the latter soil, than in soil d. Furthermore the different nitrification energies of the different soils do not seem to influence the thrift of *Tussilago* and *Poterium*.

It holds good of all the plants experimented on that the more acid soil they were groing in, the darker were their leaves.

Experiments on the growth of different species in nutrient liquids with different hydrogen ion concentrations. The first experiments were made during the summer 1917, and were made on the acid soil plants *Deschampsia flexuosa, Senecio silvaticus, Sphagnum rubellum, S. magellanicum, S. apiculatum*

and *S. subsecundum* and on the alkaline soil plants *Tussilago farfarus* and *Hordeum distichum*[1]) as also on the aquatic plant *Helodea canadensis*.

At these experiments it was a question of keeping the hydrogen ion concentration of the nutrient liquids constant during the period of experiment. As it was not possible to add any buffer substances in greater quantities to the nutrient liquids because their salt concentration might be higher than the plants could stand, a "running-water-culture" was used, i. e. the plants were cultivated under such conditions that the nutrient liquids incessantly were renewed.

As the plants were to be cultivated in nutrient liquids of 6 different hydrogen ion concentrations 6 carboys each holding 60 litres of nutrient liquids were placed in the green house in a proper height. On each carboy a glass tube was placed acting as a siphon, from which the nutrient liquid was conducted to the different culture glasses through a glass distributor. By means of intercalated rubber-tubes provided with pinch-cocks the supply of the liquid could be regulated. The nutritive liquids were lead to the surface of the culture glasses, while a self-regulating glass siphon from the bottom of the glasses lead the surplus nutrient liquid away. The supply of nutrient liquid was regulated so that the liquid in the glasses was renewed about 3 times in the 24 hours.

For the preparation of the nutrient liquids tap water was used. One litre of the prepared nutrient liquid contained:

0.075 g KNO_3
0.035 - $MgSO_4, 7H_2O$
0.050 - $CaCl_2, 6H_2O$
0.025 - KH_2PO_4

besides the substances[2]) originately found in the tap water. Besides the quantity of hydrochloric acid or sodium hydroxyde solution required to give the nutrient liquid the desired hydrogen ion concentration, was added to each of the 6 nutrient liquids.

When the nutrient liquids in the carboys were used, new

[1]) The material of seed sown originating with a "pure line" of Goldthorpe barley was kindly supplied by Professor W. Johannsen.

[2]) The tap water contained in one litre 0.18 g Ca and so much iron that it was superfluous to add a ferric salt to the nutrient liquid.

nutrient liquids were prepared by introducing in the empty carboys the single nutritive salts as concentrated solutions together with the quantity of acid or base necessary for each nutrient liquid; then the carboys were filled with tap water. The nutrient liquid was carefully mixed by conducting a strong current of air; then its hydrogen ion concentration was colorimetrically measured and possibly corrected by adding a little hydrochloric acid or sodium hydroxyde solution. Besides the hydrogen ion concentration was also controlled in the culture glasses regularly during the period of the experiment.

The six different nutrient liquids severally had the following p_H values: 3.5; 4.5; 5.5; 6.5; 7.5; 8.0.

The *Sphagnum* species and *Helodea* were cultivated in cylindric glasses holding 0.5 litre, the other plants in wide-necked intransparent glass bottles, also holding 0.5 litre. The plants were placed in the glasses on perforated cork-stoppers where they were fastened by means of glass cotton.

Deschampsia flexuosa, Hordeum distichum, Senecio silvaticus and *Tussilago farfarus* were made to germinate in sand and having reached a suitable size they were placed in the culture glasses. Of *Deschampsia flexuosa* 10 plants were placed in each glass.

Of *Helodea* about two g of fresh shoots were placed in each glass, of the submerged *Sphagnum subsecundum* 3 g, of *S. rubellum* and *S. magellanicum* 5 g, and of *S. apiculatum* 15 g. The three latter non-submerged species were placed in the glasss, so that the top of the shoots were on a level with the brim of the glass and rose about 2 cm above the surface of the liquid. The shoots of the 5 last mentioned species were gathered in Nature.

Double series of all the experiments were made. The cultivation in water culture began as regards all the species on the 22nd of May.

During the period of the experiment it held good of all the species, *Helodea* however expected, that hardly any growth took place in the two alkaline nutrient liquids, in which the plants quickly became chlorotic, while the *Sphagnum* plants in these two nutrient liquids quickly died. In the slightly acid nutrient liquid, the p_H value of which was 6.5, the two acid soil plants *Deschampsia flexuosa* and *Senecio silvaticus* quickly became

chlorotic and only grew very slowly, while *Tussilago* and *Hordeum* in the same nutrient liquid remained pure green and reached a vigorous growth[1]).

It held good of all the species that when cultivated in the most acid nutrient liquids in which they could thrive they assumed a darker green colour than in the less acid ones.

Moreover it must be stated that the plants during the first fortnight of the period of the experiment did not show as great differences in the growth in the different nutrient liquids as later. *Tussilago* and *Hordeum* even grew somewhat more at the beginning in the nutrient liquid the p_H value of which was 5.5 than in that with a p_H value of 6.5, while the case was nearly the reverse later. At the first stages of development the plants thus comport somewhat otherwise than later; consequently when only using a fortnightly period for the experiments — as was made by the said American investigators (Hoagland 1917, Sal-

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[1]) Stohmann (1862) already observed that the higher plants, most aquatic plants however excepted, do not thrive in an alkaline nutrient liquid, in which they quickly will become chlorotic. The reason of the plants becoming chlorotic when growing in a nutrientl iquid giving an alkaline reaction is generally considered to be that the plants cannot absorb the iron, because it is in a precipitated condition. Gile and Carrero (1916) have also substantiated that chlorotic rice plants cultivated in a nutrient liquid giving alkaline reaction contained less iron than rice plants cultivated in acid nutrient liquids.

Besides I have not been able in any of the nutrient liquids used at the above mentioned experiments, not even in the alkaline ones, to observe the least trace of deposit. Therefore it is not immediately obvious that the chlorosis of the plants in the alkaline nutrient liquids is due to the fact that the iron is not accessible, because it is in a precipitated condition. If the reason of the chlorosis is that the iron is found in a precipitated condition, it is difficult to understand that the acid soil plants become chlorotic in a nutrient liquid, the p_H value of which is 6.5, while the alkaline soil plants do not become chlorotic in such a nutrient liquid, for if the acid soil plants cannot absorb the iron, because it is found in a precipitated condition, the alkaline soil plants must be able to do so, as they do not become chlorotic in a nutrient liquid, the p_H value of which is 6.5. The matter cannot be explained by assuming that the alkaline soil plants may put up with less iron than the acid soil plants, for, as mentioned on p. 5 alkaline soil plants generally contain as much iron as the acid soil plants.

Gile and Carrero (1916) state that it is possible to cultivate plants in an alkaline nutrient solution so as partly to avoid chlorosis, viz. in the case when iron is given as tartrate, in which case it is not precipitated because it enters in a complex ion. Experiments which I have made with barley plants, do not corroborate the correctness of this statement.

Table 35.

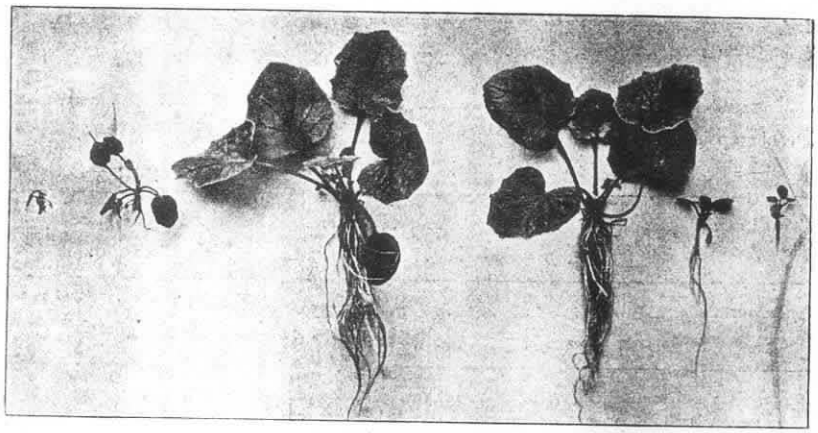
The growth of different plants of different hydrogen ion concentration. The numbers state the weight of the plants in g at the end of the experiments.

p_H values of the nutrient liquids	3.5	4.5	5.5	6.5	7.5	8.0
Sphagnum rubellum, fresh	22.0	14.0	dead			
— — , dried	1.8	1.3				
Sphagnum magellanicum, fresh	18.0	12.0	dead			
— — , dried	1.7	1.0				
Deschampsia flexuosa (10 plants), fresh	4.0	**4.5**	3.0	1.7	dead	
— — (10 —), dried	0.6	**0.7**	0.5	0.3		
Senecio silvaticus (1 plant), fresh	21.0	**25.0**	15.0	5.0	1.0	dead
— — (1 —), dried	2.8	**3.2**	2.0	0.6	0.2	
Sphagnum apiculatum, fresh	31.0	**35.0**	20.0	dead		
— — , dried	3.3	**4.0**	2.1			
Sphagnum subsecundum, fresh	4.3	5.2	**6.0**	4.3	dead	
— — , dried	0.3	0.5	**0.6**	0.4		
Hordeum distichum (1 plant), fresh	3.0	45.0	86.0	**88.0**	10.0	4.0
— — (1 —), dried	0.4	6.3	13.0	**13.0**	1.4	0.6
Tussilago farfarus (1 plant), fresh	dead	7.0	30.0	**35.0**	2.0	1.0
— — (1 —), dried		1.1	4.0	**4.2**	0.3	0.2
Helodea canadensis, fresh	dead		2.6	3.3	4.4	**6.4**
— — , dried			0.2	0.3	0.4	**0.7**

ter and Mc Ilvaine 1920), other results will be reached than when using a longer period.

All the experiments were finished on the 21st of July, thus after a period of about two months. The plants were weighed after the expiration of the experiments, first in fresh condition, later in dried condition. The result will be seen from table 35. The plants from the duplicate cultures were in good conformity as regards the weight, consequently this is stated in the table as the average value. It will be seen from the table that the diffe-

rent species reached their most vigorous growth at very different hydrogen ion concentrations. *Deschampsia flexuosa* and *Senecio silvaticus* which in Nature only are found in very acid soils, reached their best growth in the nutrient liquid, the p_H of which was 4.5, the alkaline soil plants *Tussilago farfarus* (see fig. 8) and *Hordeum distichum* in the nutrient liquid, the p_H value of which was 6.5. None of the plants with which experiments have been made could thrive in alkaline nutrient liquids, the aquatic



p_H 3.5 4.5 5.5 6.5 7.5 8.0

Fig. 8. The growth of *Tussilago farfarus* in nutrient liquids of different hydrogen ion concentration. Phot. 21/7 1917.

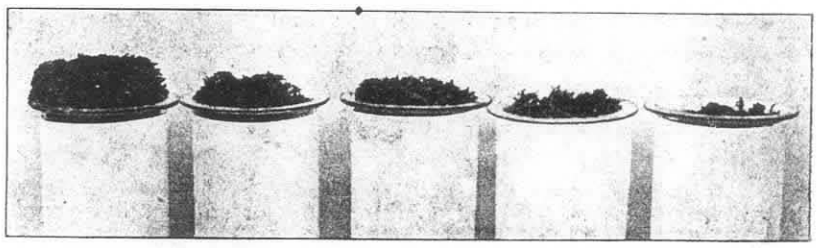
plant *Helodea canadensis* however excepted. The latter has even its most vigorous growth in the most alkaline of the nutrient liquids, and as will be known it is also found in Nature in very calcareous, i. e. alkaline waters. It is besides — as mentioned above (p. 110 the foot-note) — a well-known case that aquatic plants contrary to other plants can thrive in alkaline nutrient liquids.

The *Sphagnum* species were able to thrive in nutrient liquids, the hydrogen ion concentration of which lies within narrow limits (see fig. 9 and 10). *S. rubellum* and *S. magellanicum* are — as will be known — specific high moor plants and in conformity herewith they were thriving best in the most acid liquids; *S. apiculatum*, which as a rule in Nature is found in less acid growing substratum than the two first mentioned species, were thriving best in nutrient liquids the p_H values of which

was 4.5. Finally the submersed *S. subsecundum* showed its best thriving in nutrient liquids the p_H value of which was 5.5. The plants of this species originated with Store Grib Sø, the water of which has a hydrogen ion concentration of 5.3 expressed in p_H.

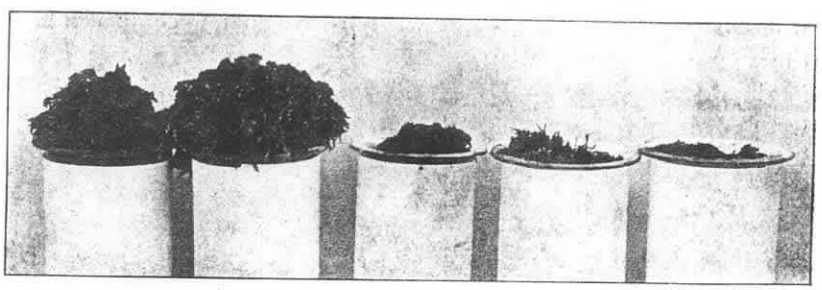
During the summer 1920 another series of experiments was made with *Deschampsia flexuosa*, *Senecio silvaticus* and *Tussilago*

Fig. 9—10 show the growth of two different *Sphagnum* species in nutrient liquids of different hydrogen ion concentrations.



p_H 3·5 4·5 5·5 6·5 7·5

Fig. 9. *Sphagnum rubellum*. Phot. $^{21}/_{7}$ 1917.



p_H 3·5 4·5 5·5 6·5 7·5

Fig. 10. *Sphagnum apiculatum*. Phot. $^{21}/_{7}$ 1917.

farfarus. A running water culture was, however, not used, but they were placed as is generally the case with water culture experiments, with the only difference that during the whole period a constant current of atmospheric air was conducted through each single nutrient liquid. This "airing" of the nutrient liquids appeared to have an extremely beneficial influence on the growth of the plants, and hereby was moreover obtained that the carbonic acid disengaged at the root respiration was removed.

During the period of the experiments the hydrogen ion con-

centrations of the nutrient liquids were measured every second day and, if necessary, corrected by adding hydrochloric acid or sodium hydroxyde solution. In this way the hydrogen ion concentration was kept constant in the different liquids. Besides the nutrient liquids were renewed once during the period of the experiments.

As nutrient liquid was used boilt and filtered tap water to which was added to each litre:

1.12 g $NaNO_3$
0.30 - NH_4Cl
0.25 - $MgSO_4, 7H_2O$
0.25 - $CaSO_4, 2H_2O$
0.25 - KCl
0.25 - KH_2PO_4
0.01 - $FeCl_3$

beside the quantity of hydrochloric acid or sodium hydroxyde solution necessary to give the solutions the desired hydrogen ion concentration. Nutrient liquids were used, the hydrogen ion concentration of which expressed in p_H varied from 2—7.5. It will be seen from table 36 at what hydrogen ion concentrations the single species were cultivated. All the cultures were made in duplicate. After having germinated in moist sand the plants were placed in the culture glasses on the 1st of June. The ex-

Table 36.

The growth of 3 different species in nutrient liquids of different hydrogen ion concentrations. The numbers state the weight of the plants in g at the end of the experiment.

p_H values of the nutrient liquids	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	6.5	7.0	7.5
Deschampsia flexuosa (10 pl.), fresh	0.4	1.0	3.5	»	**5.2**	»	4.0	2.1	1.8	0.4	»
— — (10 —), dry.	0.1	0.2	0.6	»	**0.8**	»	0·6	0.3	0.3	0.1	»
Senecio silvaticus (1 plant), fresh.	»	»	1.5	18.0	**26.0**	»	18.0	14.0	4.2	1.3	»
— — (1 —), dry..	»	»	0.3	2.2	**3.4**	»	2.3	2.0	0.5	0.2	»
Tussilago farfarus (1 plant), fresh.	»	»	»	0.6	6.2	8.7	10.3	**20.5**	»	**20.0**	0.4
— — (1 —), dry..	»	»	»	0.1	0.8	1.2	1.4	**2.5**	»	**2.5**	0.1

Fig. 11—13 show the growth of different species in nutrient liquids of different hydrogen ion concentrations.

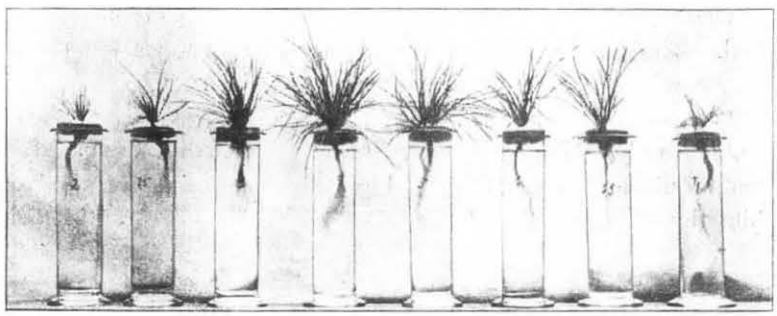


Fig. 11. *Deschampsia flexuosa.* Phot. 1/8 1920.

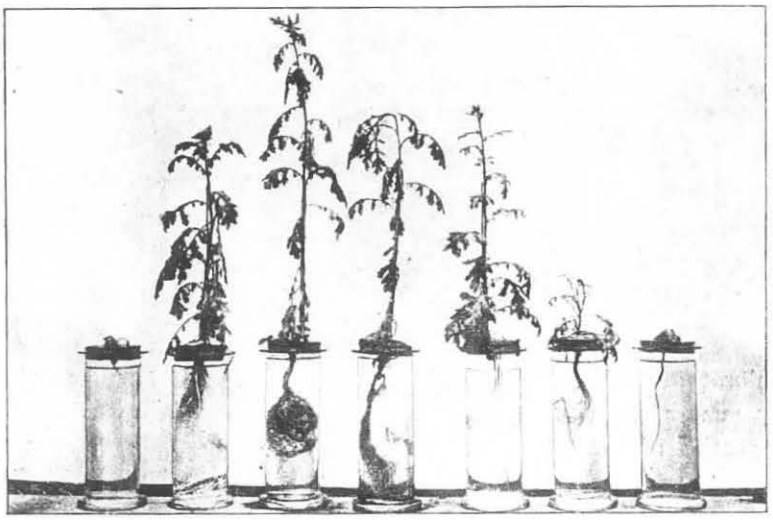


Fig. 12. *Senecio silvaticus.* Phot. 1/8 1920.

Fig. 13. *Tussilago farfarus.* Phot. 1/8 1920.

periment was finished on the 1st of August (see fig. 11, 12 and 13) when the plants were weighed first in fresh condition, later dried. The result will be seen from table 36.

As was the case at the experiment in 1917, the acid soil plants *Deschampsia flexuosa* and *Senecio silvaticus* became chlorotic, not only in the alkaline, but also in the slightly acid nutrient liquids, the p_H values of which were 6.0 and 6.5 respectively, while the alkaline soil plant *Tussilago farfarus* did not become

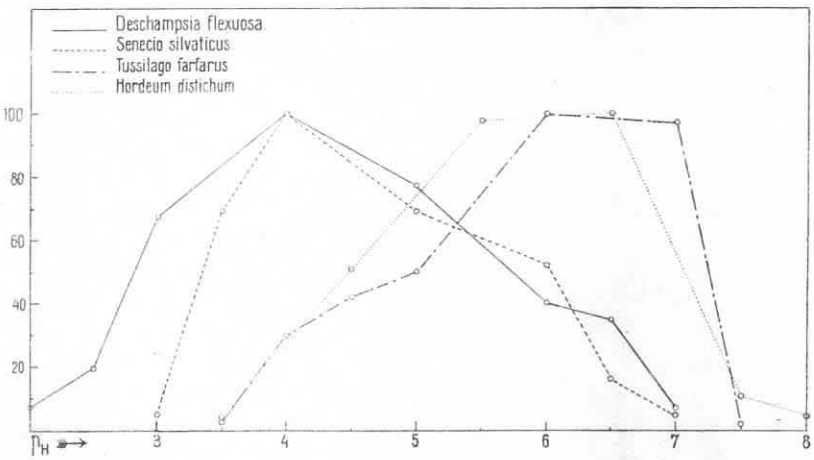


Fig. 14. The relative growth of four different species in nutrient liquids of different hydrogen ion concentrations.

chlorotic in the slightly acid liquids, in which it even reached its most vigorous growth. Besides it will be seen from the table that the results of the experiments are in fair conformity with the corresponding one of 1917, although the nutrient liquids had an essentially different composition and i. a. was remarkable for a far higher salt concentration.

The relative growth of the three species at different hydrogen ion concentrations has been graphically represented in fig. 14, as the highest weight reached for each single species has been equalized to 100 and the other weight figures are converted in relation hereto. In the same figure is stated the relative growth of *Hordeum distichum* calculated at the experiments of 1917. The figure thus represents the growth of two acid soil plants and two alkaline soil plants at different hydrogen ion concentrations. As will be seen, the graphs of the acid soil plants and alkaline soil plants differ very much.

It appeared from all the experiments, as will be seen from the preceding observations, that no land plants, not even alkaline soil plants, can thrive in alkaline nutrient liquids, while the alkaline soil plants on the other hand thrive excellently in alkaline reacting soils and also, as will be seen from the following, in an alkaline reacting sand culture. An explanation is necessary here. When an alkaline soil plant cannot thrive in alkaline reacting liquid, it is a natural conclusion that the plant cannot thrive either in the soil, if the soil liquid round the roots gives an alkaline reaction. If the plant thrives very well in an alkaline reacting soil, i. e. a soil the aquaous extract of which is alkaline, the conclusion may be drawn that the soil liquid round the roots of the plants does not react alkaline, but gives a slight acid reaction. The slightly acid reaction which must be supposed to dominate in the membranes of liquid round the roots, is doubtless brought about by the carbonic acid disengaged at the root respiration, as these membranes of liquid round the roots probably may be nearly saturated with carbonic acid[1]). If alkaline reacting calcareous soil is deposited in water, and if the mixture is saturated with carbonic acid, the hydrogen ion concentration will increase to a value of about 6.0 expressed in $p_{H'}$, this hydrogen ion concentration being extremely favourable to an alkaline soil plant; even at considerably lower tension of carbonic acid the hydrogen ion concentration might easily reach a $p_{H'}$ value lower than 7. Besides there is no reason to suppose that alkaline soil plants disengage greater quantities of carbonic acid from the roots than acid soil plants. The latter can without doubt also in calcareous soil increase the hydrogen ion concentration in the liquid round the roots to a value which expressed in $p_{H'}$ lies between 6 and 7, but as it will be seen from

[1]) If the carbonic acid in an alkaline reacting liquid constantly is removed from the surroundings of the roots, e. g. by running water, a bad thriving in connection with chlorosis even in calciphilous plants may be observed also under natural conditions. On a chalk cliff at Blaakilde near Skørping where *Tussilago farfarus* and *Urtica dioeca* were growing, the water at several places leaked out from the cliff. The very calcareous water had a neutral reaction ($p_{H'}$ = about 7.0) where oozing directly out of the cliff and the plants that grew here showed a normal green colour, but at some distance from these places both *Tussilago* and *Urtica* were found to be chlorotic, and the water which incessantly run over the soil and the roots showed an alkaline reaction ($p_{H'} = 7.5—8.0$) having gradually given off part of its carbonic acid.

Table 37.

Summary of the germination of different species in nutrient liquids with different hydrogen ion concentrations.

p_H of the nutrient liquids	3.0	3.5	4.0	4.5	5.5	6.5	7.5	8.0
Deschampsia flexuosa	germination normal, several root-hairs were developed						germination slow, germ root remains short and without root-hairs	
Arnica montana	germination slow, no root-hairs developed	germination normal, several root-hairs were developed					do.	
Senecio silvaticus	do.	germination slow, root-hairs were developed	germination normal, several root-hairs were developed				germination slow, germ root thin, almost without root-hairs	
Chamaenerium angustifolium	do.	do.	do.				germination slow, root-hairs scarce	
Poterium sanguisorba	germ root developed, but immediately turns brown at the point and dies		germination slow, root-hairs scarce	germination normal, several root-hairs developed			do.	
Tussilago farfarus	do.		do.	do.			do.	

the experiments, such a hydrogen ion concentration is too small to have the plants reach a normal growth.

It will appear from what has been stated that the hydrogen ion concentration also in acid soils on account of the secretion of carbonic acid of the roots must be higher in the soil liquid in the immediate surroundings of the roots than in the soil liquid as a whole. The difference, however, must be decreasing with the increasing hydrogen ion concentration of the soil, and at a p_H value of 4 or lower values the carbonic acid cannot any more exercise any influence on the hydrogen ion concentration.

Experiments on the germination of different species in liquids with different hydrogen ion concentrations[1]. In May

[1]) Germination experiments in liquids containing different quantities of acid and base have been made by Loew (1903), Fischer (1907), Promsy (1911),

1918 germination experiments were made with *Deschampsia flexuosa*, *Arnica montana*, *Senecio silvaticus*, *Chamaenerium angustifolium*, *Poterium sanguisorba* and *Tussilago farfarus* in nutrient liquids of different hydrogen ion concentrations. The germination took place in conical flasks closed with a cotton wool plug. The nutrient liquid had the same composition as that described on p. 108, and in each flask so much was put as to cover the bottom with a layer of the liquid that was 5 mm thick. During the experiment that lasted for about a fortnight, the nutrient liquids were changed daily. Each species was sown in nutrient liquids of 8 different hydrogen ion concentrations, as will be seen from table 37.

The different values of the hydrogen ion concentration did not influence the germination percentage, as nearly all seeds and fruits germinated, but on the other hand the quality of the germination, as will appear from table 37. It will be seen, that the different species have a greater or smaller range of hydrogen ion concentration, in which the germination is normal, and that the acid soil plants are able to germinate normally at higher hydrogen ion concentrations than the alkaline soil plants.

Have ammonia salts and nitrates different values as source of nitrogen for acid soil plants and for alkaline soil plants?

As shown in section A, the greater quantities of ammonia are found in the most acid soils, while only extremely small quantities of ammonia are found in the less acid, in the neutral and in the alkaline soils, as the ammonia nitrogen here quickly is passed into nitrate. As mentioned on p. 11, a number of investigators have, therefore, thought that the species found on very acid soil (acid soil plants) can use ammonia, while those

• Crocker and Davis (1914) and Onodera (1916). It holds good of these experiments as of those mentioned on p. 102 that as no regard is paid to the hydrogen ion concentration they are of very little interest. Germination experiments with maize, wheat, soya-beans and alfalfa in liquids of different hydrogen ion concentrations have been made by Salter and Mc Ilvaine (1920). They found that the said species are able to germinate at somewhat higher hydrogren ion concentration than the plants can stand later during their growth.

found on alkaline soil (alkaline soil plants) require nitrate as the source of nitrogen and cannot use ammonia, which as regards these plants is considered a less favourable source of nitrogen. Experiments, however, have not been made in order to have the theory in question corroborated. On the other hand, there is a rather considerable literature on the value of ammonia nitrogen and nitrate nitrogen as the source of nitrogen for the culture plants[1]).

It appears from this literature that the nitrogen nitrate nearly always has appeared to be a favourable source of nitrogen for the higher plants, while ammonia salts have given very different results; in some cases they have proved useful, in other cases less useful as source of nitrogen, in numerous cases they have even had a very disadvantageous effect. Thus as early as 1868 Hellriegel states that when using ammonia salts as source of nitrogen in his sand cultures he never got normal plants. Hampe (1868) and Beyer (1869) also reached bad results when using ammonia salts as source of nitrogen for plants in water culture; the plants grew rather well at first but died later pretty suddenly. Wagner (1869) reached rather good results with maize in water culture when using ammonia phosphate as a source of nitrogen, while the result when using ammonia carbonate was very bad. Hässelbarth (1878) found that nitrates had a far better effect in sand culture on barley than ammonia salts, which might give good results when marl was added at the same time, the advantageous effect of which Hässelbarth ascribes to its furthering effect on the nitrification. Heiden (1879) has, when using ammonia sulphate as nitrogen fertilizer at field experiments reached worse results than when not giving nitrogen fertilizer at all. Kellner (1884) has shown, that rice is thriving as well with ammonia salts as with nitrates and that this plant in the rice fields cannot have any nitrate whatever as the nitrification does not take place here[2]). Pitch (1887, 1893 and 1896) in order to avoid the nitrification has cultivated barley and oats sterily in sterilized soil both with nitrates and with ammonia salts and reached the best results when using nitrates; oats, however, was

[1]) A very elaborate list of literature is found in Wolkoff (1918 II).

[2]) Statements found in several phyto-physiological text-books to the effect that ammonia salts are a favourable source of nitrogen to fen- and moor-plants are surely derived herefrom.

thriving comparatively better than barley when using ammonia salts as nitrogen fertilizer.

The opinion of the reason of the unfavourable effect of ammonia salts is varying. Mayer (1881) draws the attention to the fact that ammonia sulphate and ammonia chloride have a "physiologically acid effect", i. e. that when used as fertilizer they involve that the reaction of the soil is altered in acid direction, which he thinks is due to the plants using the base of the salts (NH_4OH), while the acids are left in the soil. It is the contrary with nitrate of soda, as the reaction of the soil when this substance is used is altered in an alkaline direction, which he thinks may be explained by the plants in this case using the nitric acid, whereby the base is left in the soil. This substance, therefore, is described as being "physiologically alkaline".

Several authors therefore have been of opinion that the physiologically acid nature of the ammonia salts is the reason of their disadvantageous effect, as the growing medium gradually should become so acid, that the acid reaction has a directly injurious effect on the roots, e. g. Ehrenberg (1908), who found, that plants in sand culture suffered heavily from supply of ammonia phosphate, while they were thriving well when having potassium nitrate. At the end of the experiment it appeared that the culture medium (consisting of sand mixed with a little high moor peat) gave a very acid reaction on the litmus paper in the vessels to which ammonia salts had been added, while the vessels to which potassium nitrate had been added only gave a slightly acid or nearly neutral reaction (however, it must be remembered that the culture medium on account of the high moor peat from the beginning must have given a very acid reaction). In a later paper (1910) Ehrenberg, however, means that the injurious influence of the ammonia salts is due not so much to their physiologically acid quality as to the fact that the vessels used for these experiments nearly always are made of zinc, and this metal according to Ehrenberg is said to be able to liberate the base (NH_4OH) from the ammonia salts, the hydroxyl ions of which then have a corrodent effect on the plant roots (l. c. p. 129).

That ammonia salts when used as fertilizer cause the quantity of acid in the soil to increase has many times later been

observed, thus by Daikuhara (1914, p. 1), Truog (1918, p. 184), and by Allison and Cook (1917) who state that although to a smaller degree this also takes place when the soil is uncovered, which — they think — is due to the consumption of nitrogen of the microorganisms. Furthermore it has many times been substantiated that heavy soluble phosphoric acid fertilizer when given together with ammonia sulphate becomes more easily accessible for the plants than if ammonia salts are not given at the same time (Prianischnikow 1902, Böttcher 1907, Söderbaum 1908, Mitscherlich and Simmermacher 1913); this is explained, at any rate partly, by the physiologically acid character of the ammonia salts.

Experiments with ammonia salts as source of nitrogen in arable soils have, however, in many cases given rather good results (Lipman and Gericke 1918). The different species react different to ammonia salts (Wolkoff 1918), and the same holds good of the soils, as ammonia salts often on sandy soils give worse results than on clayey ones (Haselhoff 1914). Lipman and Blair (1918), however, mean that ammonia sulphate in all cases is a worse nitrogen fertilizer than nitrate of soda.

Several investigators have thought it possible to explain the less advantageous effects in many cases called forth by ammonia salts not as a consequence of their physiologically acid qualities, but as a consequence of ammonia ions simply being toxic to the plants, thus Allison (1918), Wolkoff (1918 I and II) and Söderbaum (1910, 1915, 1916, 1917, 1918). The last-mentioned investigator has at vessel experiments with a sand soil substantiated decidedly injurious effects called forth by ammonia salts on barley and wheat, while a quantity of nitrate of soda equivalent to the given quantity of ammonia salts used as fertilizer in the same soil gave excellent results. When fertilizing with increasing quantities of ammonia sulphate decreasing yield was obtained with wheat; where larger quantities of ammonia sulphate were used, the yield was smaller than in the vessels to which no nitrogen fertilizer was added. Oats, rye and potatoe were contrary to barley and wheat, as these plants gave as good yield when fertilized with ammonia sulphate as when using nitrate of soda. Different ammonia salts were tried on barley, which all proved injurious to a different degree (Söderbaum 1917). Thus ammonia chloride had the most toxic effect, then

comes arranged after the decreasing toxicity the sulphate, the nitrate, the carbonate and the phosphate. The injurious effect of the salts partly manifested itself in a great chequing of the growth, partly in the leaves, that had developed, quickly becoming brown in the point; they often quite faded later. Based on these observations Söderbaum is of opinion that the ammonia ions have toxic effects, as from reasons to which I shall later revert he thinks, that it cannot be a question of the physiologically acid effects of the salts (Söderbaum 1915, p. 10).

Söderbaum's experiments thus seem to corroborate the above mentioned theory, according to which acid soil plants shall be able to use ammonia nitrogen, what the alkaline soil plants on the other hand cannot do, for the ammonia salts at his experiments proved toxic to the plants which require a limy soil for their good thriving, i. e. the alkaline soil plants (barley and wheat), while ammonia salts were not toxic to the plants thriving well in acid soil (potatoe, rye and oats).

To examine how alkaline soil plants and acid soil plants are thriving, both when having ammonia salts and when having nitrates as source of nitrogen, I made during the summer 1918 a number of sand culture experiments with *Deschampsia flexuosa*, *Eriophorum vaginatum*, *Senecio silvaticus*, *Chamaenerium angustifolium*, *Oxalis acetosella*. *Asperula odorata*, *Mercurialis perennis*. *Poterium sanguisorba* and *Tussilago farfarus*.

The sand that was used at the experiments was strand sand which was washed first with hydrochlorid acid then with tap water, until the water did not give an acid reaction any more. Finally the sand was washed with distilled water and then dried.

The vessels in which the plants were cultivated were cylindrical earthen jars, glaced within, with a bottom area of about 250 cm² and holding 5.5 kilos dry sand. Each receiver got the following fertilizer:

1 g $CaSO_4$, 2 H_2O
1 - $CaHPO_4$, 2 H_2O
1 - KCl
0,5 - $MgSO_4$, 7 H_2O
0,02 - $FeCl_3$.

The two first mentioned substances were in powdered condition mixed with the dry sand. The other substances were

added in solution, one half immediately at the beginning of the experiment, the rest 6 weeks later.

All the plants with which experiments were made were cultivated in three different ways, viz. partly with ammonia chloride, partly with ammonia nitrate and partly with sodium nitrate as source of nitrogen. The quantity of nitrogen was in all cases the same. In order to reach the natural conditions as much as possible, the nitrogen was not added at a time, but every week 25 mg of nitrogen was added to the jars, thus

95.4 mg NH_4Cl, 71.4 mg NH_4NO_3, 151.7 mg $NaNO_3$

respectively. The nitrogen compounds were added dissolved in the water used at the watering. The cultures remained in a green house and during the period of the experiments the plants were watered with distilled water not containing copper.

In the cultures in which ammonia salts were used as source of nitrogen, the nitrification had of course to be prevented. To attain this, an absolute sterile culture which it is extremely difficult to carry through, is not necessary, for as the nitrification bacteria cannot stand drying up (Lafar 1904—1906) they are not found in the air. At a temporary experiment it also appeared that no nitrification takes place in moist sand, to which is added ammonia chloride, when care is taken that the sand does not get into touch with objects, which have been brought into contact with moist soil. To be quite sure that no nitrification of the ammonia nitrogen takes place at the experiment, the sand in the jars to which ammonia chloride was added, was often controlled partly by trying whether nitrate might be shown in the sand by means of diphenylamin sulphuric acid, partly by inoculating Winogradsky's solution (see Lafar 1904—1906, p. 146) with a little of the sand. Traces of nitrate in the sand have never been shown, nor could samples of the sand bring about nitrification in Winogradsky's solution. It may, therefore, be supposed that nitrification during the experiment has not taken place in any of the cultures.

Deschampsia flexuosa, *Eriophorum vaginatum*, *Senecio silvaticus*, *Chamaenerium angustifolium* and *Poterium sanguisorba* were sown in the jars on the 15th of April, *Tussilago farfarus* on the 8th of May. *Mercurialis perennis*, *Oxalis acetosella* and *Asperula odorata* on the other hand were placed in the sand as under-

ground shoots, which first had been sterilized by aid of a 2 per cent sublimate solution. To give the plants shade enough the culture of the three wood-plants were placed below a tent of green tissue-paper, through which about 7 per cent of the day light might pass.

All the cultures were made in duplicate. In the jars, in which the plants were sown, a thinning was made as soon as the plants had developed, leaving an equal number of plants of each species in each jar. The period of the experiments was, as will appear from table 39 (p. 130), of uneven length for the different species, the experiments with the slowly growing species being extended over a longer period than those with quickly growing ones.

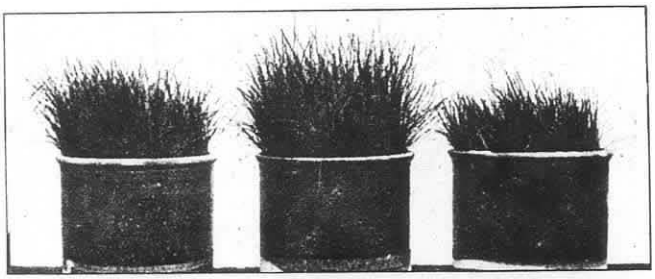
During the period the different species were very different.

At the experiments where the plants got ammonia chloride, the different species comported themselves as follows: *Poterium* and *Tussilago* as early as a week after the germination assumed a deep green colour; about 5 days afterwards they began to fade and finally died after having developed only one or two small leaves. *Mercurialis*, *Asperula*, *Oxalis* and *Chamaenerium* also faded after first having assumed a deep green colour, this however only taking place after 3—4 weeks after the beginning of the experiment. *Senecio* on the other hand grew for a long time and reached a rather considerable development; not until the 27th of June the plants began to fade and finally died. Only *Deschampsia* and *Eriophorum* thrived during the whole period of the experiment.

With ammonia nitrate as source of nitrogen *Deschampsia*, *Eriophorum*, *Senecio*, *Chamaenerium*, *Oxalis* and *Asperula* developed excellently (fig. 15—20). *Mercurialis*, *Poterium* and *Tussilago* also grew well at the beginning, the growth at a given time even being more vigorous than in the cultures in which sodium nitrate was source of nitrogen (see fig. 23), but at the end of July the three said species began to turn very dark green and at the beginning of August they began to fade and finally died (see fig. 21, 22 and 24).

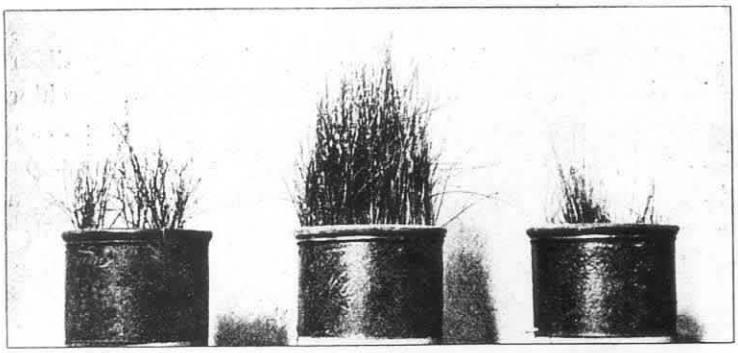
With sodium nitrate as source of nitrogen *Tussilago*, *Poterium* and *Mercurialis* reached their best growth (fig. 21, 22 and 24), while the other species showed a very slow growth (fig. 15

Fig. 15—24. The growth of different plants in sand culture with ammonia chloride, ammonia nitrate and sodium nitrate respectively as source of nitrogen.



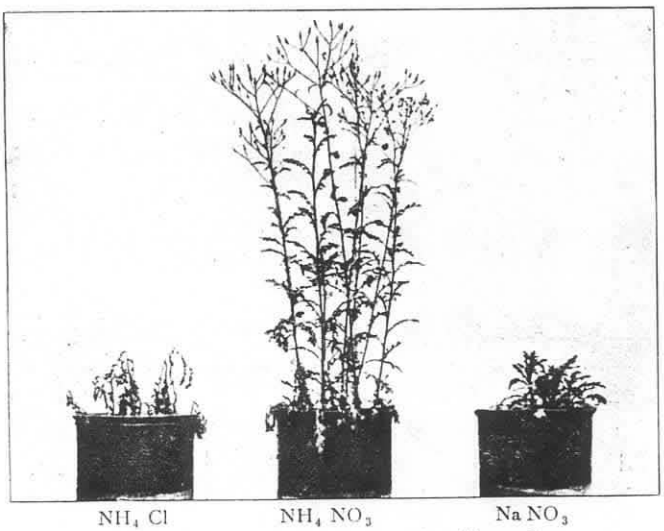
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 15. *Deschampsia flexuosa.* Phot. 14/7 1918.



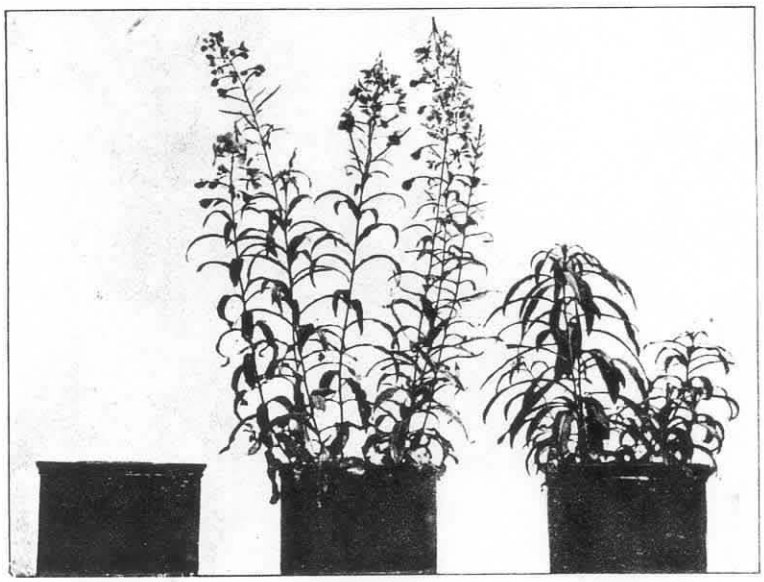
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 16. *Eriophorum vaginatum.* Phot. 14/9 1918.



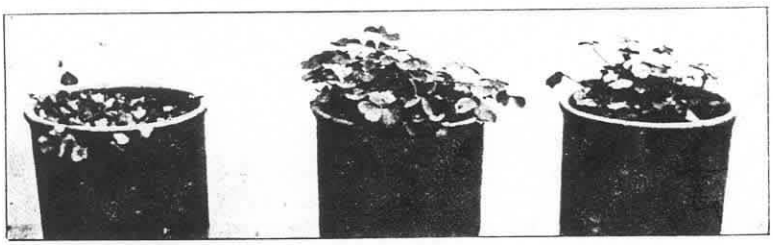
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 17. *Senecio silvaticus.* Phot. 3/7 1918.



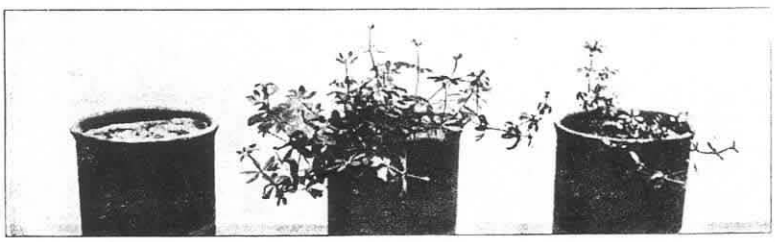
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 18. *Chamaenerium angustifolium*. Phot. 17/7 1918.



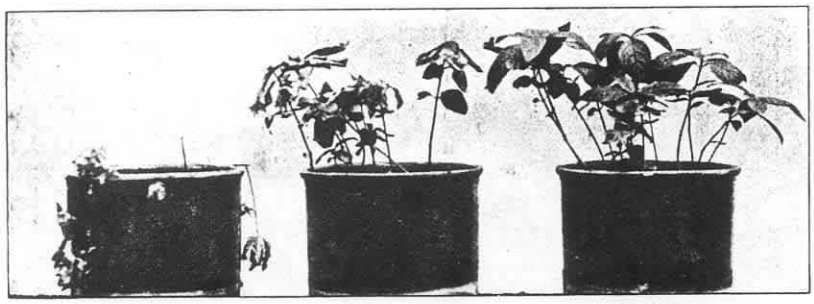
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 19. *Oxalis acetosella*. Phot. 17/7 1918.



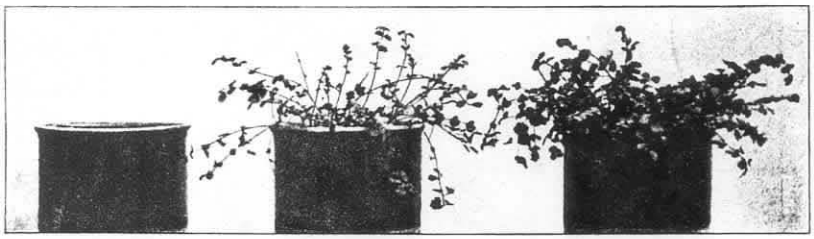
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 20. *Asperula odorata*. Phot. 17/7 1918.



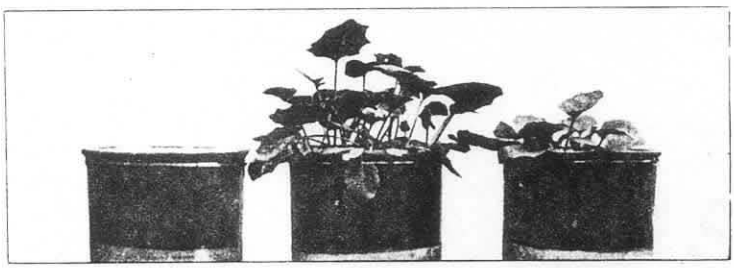
NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 21. *Mercurialis perennis.* Phot. $^{17}/_{7}$ 1918.



NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 22. *Poterium sanguisorba.* Phot. $^{8}/_{8}$ 1918.



NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 23. *Tussilago farfarus* The appearance of the cultures about $1^{1}/_{2}$ month after the beginning of the experiment. Phot. $^{20}/_{9}$ 1918.

NH_4Cl NH_4NO_3 $NaNO_3$

Fig. 24. *Tussilago farfarus.* Same cultures as those seen in fig. 23 but about 2 months later. Phot. $^{28}/_{8}$ 1918.

Table 38.

The p_H values of the nutrient liquids absorbed by the sand. * at the p_H values stated designates that the plants at the times of the determination had died.

Source of nitrogen	NH_4Cl	NH_4NO_3	$NaNO_3$
	p_H	p_H	p_H
Deschampsia flexuosa	2.8	3.5	7.5
Eriophorum vaginatum	3.2	4.0	8.0
Senecio silvaticus	3.0*	4.0	8.2
Chamaenerium angustifolium	3.0*	3.9	7.8
Oxalis acetosella	3.4*	4.0	8.0
Asperula odorata	3.4*	4.2	7.8
Mercurialis perennis	3.8*	4.2	8.0
Poterium sanguisorba	3.5*	4.0	8.0
Tussilago farfarus	3.5*	4.7	8.0

to 20) and quickly became chlorotic. The chlorosis was most marked in *Deschampsia, Eriophorum* and *Senecio.*

As evidently it was the physiologically acid reaction of the ammonia salts and the physiologically alkaline one of the sodium nitrate that was dominating, a determination of the hydrogen ion concentration[1]) of the nutrient liquid absorbed by the sand was made in all cultures; for this determination litmus paper, lacmoide paper (see Hempel 1917) and Congo paper were used. The papers were placed in the sand well moistened with distilled water and remained in contact with the sand for about half an hour. Then their colour tone was compared with the tones which were brought about by different standard liquids of known hydrogen ion concentration. The determination was made on the 3rd of July; however, as regards the cultures in which the plants had died previously, immediately after the death of the plants. The result will be seen from table 38, in which the p_H values found are stated.

In table 39 are stated the weight of the plants in dry condition[2]) at the end of the experiment as also the duration of the experiment for the single species.

[1]) The nutrient liquid originally had a p_H value of 6.

[2]) As part of the plants had faded before taken out of the sand to be weighed, their weight in fresh condition cannot be stated.

Table 39.

The weight of the plants in dry condition at the end of the experiment. The figures designate the weight in g of all the plants from a single jar.

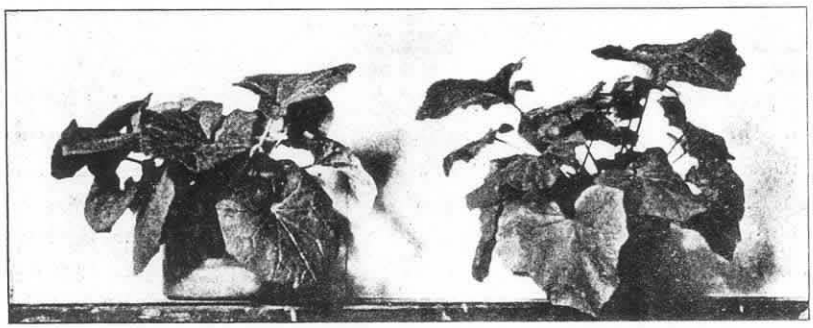
	NH_4Cl	NH_4NO_3	$NaNO_3$	Duration of the experiment
Deschampsia flexuosa	30.0	46.0	23.0	$^{15}/_{4}$— $^{1}/_{8}$
Eriophorum vaginatum	2.2	7.7	1.3	$^{15}/_{4}$—$^{14}/_{9}$
Senecio silvaticus	5.0	12.1	3.0	$^{15}/_{4}$— $^{3}/_{7}$
Chamaenerium angustifolium	0.0	17.9	11.0	$^{15}/_{4}$—$^{17}/_{7}$
Oxalis acetosella	1.0	2.7	1.6	$^{15}/_{4}$—$^{17}/_{7}$
Asperula odorata	0.0	5.9	1.2	$^{15}/_{4}$—$^{17}/_{7}$
Mercurialis perennis	0.6	8.4	11.2	$^{15}/_{4}$—$^{17}/_{7}$
Poterium sanguisorba	0.0	3.0	10.8	$^{15}/_{4}$— $^{8}/_{8}$
Tussilago farfarus	0.0	15.0	21.8	$^{8}/_{5}$—$^{25}/_{8}$

It will be clearly seen from the figures in table 38 that the disadvantageous effects of the ammonia chloride are due to its physiologically acid reaction, as the absorbtion of nitrogen involves that the hydrogen ion concentration of the nutrient liquid increases. The plants die when the hydrogen ion concentration has reached the value critical for the species, the alkaline soil plants first because these plants cannot stand comparatively high hydrogen ion concentration; the acid soil plants on the other hand are more resistant, as these plants can stand very high hydrogen ion concentrations. It must be observed that the plants of *Tussilago* and *Poterium* which died as quite small plants, had not altered the hydrogen ion concentration of the nutrient liquid of the whole quantity of sand, as only the nutrient liquid in the sand from the surface and from the immediate surroundings of the roots showed the high hydrogen ion concentration (p_H 3.5) as stated in table 38, while the nutrient liquid in the sand from the bottom of the jars had their original hydrogen ion concentration (p_H 6).

It appears from table 38, that ammonia nitrate also has a physiologically acid effect, as the plants when having this salt as source of nitrogen also brought about an increase of the hydrogen ion concentration of the nutrient liquid, although this did

not take place as quickly as when using ammonia chloride[1]). Therefore the plants were thriving for a long time when having ammonia nitrate, but as regards the alkaline soil plants the time at last came at which the hydrogen ion concentration reached the critical limit, when the plants died.

Finally it will be seen from table 38, that sodium nitrate has physiologically alkaline reaction. This is the reason of the alkaline soil plants thriving very well when having sodium ni-



NH_4Cl $NaNO_3$

Fig. 25. *Tussilago farfarus* in sand culture with ammonia chloride and sodium nitrate respectively as source of nitrogen. The sand in both jars contained calcium carbonate (levigated chalk). Phot. $^{20}/_{9}$ 1919.

trate, while on the other hand acid soil plants, which cannot stand the alkaline reaction, showed bad thriving and became chlorotic.

Thus the experiments in reality only illustrate the different ability of the species to stand high and low hydrogen ion concentrations, but nothing is elucidated as to whether ammonia or nitric acid is of different value to them as source of nitrogen. To have this question elucidated it is necessary to make the

[1]) Based on my experience I cannot say anything as to whether the plants of the ammonia nitrate absorb comparatively more ammonia than nitric acid, but it is not necessary to presume this to explain the physiologically acid reaction of the ammonia nitrate, for it must be born in mind that the other nutrients also are of importance. Apart from the nitrogen, the plants of the other nutrients absorb the greatest quantity as base (Ca, K). If now also half of the nitrogen is given as base, as is the case when ammonia nitrate is the source of nitrogen, the plants presumably of the aggregate nutrient liquid have absorbed more base than acid; consequently the hydrogen ion concentration of the nutrient liquid will increase.

Table 40.

The weight (g) of the plants at the end of the experiments.

	$NH_4Cl + CaCO_3$	$NaNO_3 + CaCO_3$
Tussilago farfarus, fresh	198.0	205.0
— — dry	25.5	27.0
Poterium sanguisorba, fresh	54.0	55.0
— — dry	11.3	12.0

experiments in such a way, that the hydrogen ion concentration in the nutrient liquid is kept constant. In sand cultures this may e. g. be reached by mixing calcium carbonate with the sand. Thus the acid liberated by the ammonia salts will be neutralized. Such an experiment was made in 1919 with *Tussilago farfarus* and *Poterium sanguisorba*. The plants in one experiment got ammonia chloride, in another sodium nitrate and the experiments were executed in the manner described above, with the only difference that the sand in all the jars was mixed with levigated chalk (200 g to 1 kilo sand). The cultivation was commenced on the 1st of June and was finished on the 20th of September. The result will be seen from table 40 and as regards *Tussilago* also from fig. 25. It will be seen that the growth of the plants was almost the same, whether having ammonia chloride or sodium nitrate.

Simultaneously with the sand culture experiment water culture experiments were made with *Tussilago farfarus* and *Deschampsia flexuosa*. Both species were cultivated partly in nutrient liquid containing ammonia chloride (solution a), partly in nutrient liquid containing sodium nitrate (solution b). The two nutrient liquids contained in 1 litre boiled and filtered tap water:

Solution a	Solution b
1.0 g NH_4Cl	1.6 g $NaNO_3$
0.25 g $CaSO_4, 2H_2O$	
0.25 - $MgSO_4, 7H_2O$	
0.25 - KCl	
0.25 - KH_2PO_4	
0.01 - $FeCl_3$	

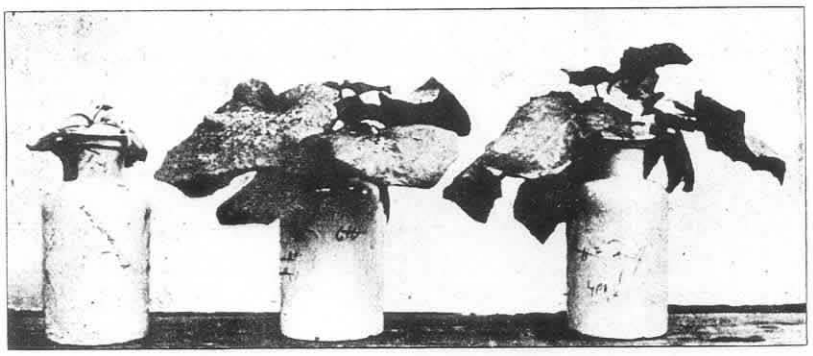
The nutrient liquids were not renewed during the period of the experiment, which lasted from the 1st of June to the 15th of August. During the whole period a constant current of atmospheric air was conducted through all the nutrient liquids.

At the experiments with *Tussilago* the p_H value of the nutrient liquid was kept constant at 6 by constantly adding sodium solution and hydrochloric acid respectively. In two cases *Tussilago*, however, was cultivated in solution *a* without making anything in order to keep the hydrogen ion concentration of the nutrient liquid constant. In these two cases the hydrogen ion concentration of the nutrient liquid increased as the plants grew until a p_H value of 3.3, after which the plants died (see fig. 26). The plants growing in the nutrient liquids the hydrogen ion concentration of which was kept constant, developed normally and showed a homogeneous growth, whether growing in solution *a* or in solution *b* (see fig. 26).

At the experiments with *Deschampsia flexuosa* the p_H values of the nutrient liquids were kept constant at 4. Also in this case the plants were homogeneously developed whether they grew in solution *a* or in solution *b*. The weight of the plants at the end of the experiment will be seen from the following table 41.

It appears from the last mentioned experiment that both alkaline soil plants and acid soil plants are thriving equally well whether ammonia salts or nitrates are given as source of nitrogen, if only the hydrogen ion concentration of the nutrient liquids is the same and is kept constant. Ammonia ions thus are not toxic for plants, neither for alkaline soil plants nor for acid soil plants. When Söderbaum when using ammonia salts as nitrogen fertilizer on barley and wheat reached very disadvantageous results, it has certainly been due to the physiologically acid reaction of the salts and not, as he thinks, to toxic effects called forth by ammonia ions. When rye, oats and potatoe were not injured, it is without doubt due to these plants being able to stand the increase of the hydrogen ion concentration of the soil, which is produced when the ammonia is absorbed by the plants. Söderbaum (1915, p. 10) thought it possible that the disadvantageous effects might be due to their physiologically acid reaction, but at closer consideration he rejected this explanation, and he stated three arguments against it. The first argument

was, that the toxic effects occurred already while the plants were quite young, and Söderbaum holds that at such an early time the plants cannot have absorbed so much nitrogen that a conside-



NH_4Cl NH_4Cl $NaNO_3$

Fig. 26. *Tussilago farfarus* in water culture. The plant to the right has got sodium nitrate as source of nitrogen and the p_H value of the nutrient liquid has been kept constant at 6.0. The plant in the middle has got ammonia chloride and the p_H value of the nutrient liquid has also been kept constant at 6.0. The plant to the left has got ammonia chloride, but nothing is made here to keep the hydrogen ion concentration of the nutrient liquid constant; therefore the plant has altered the hydrogen ion concentration to a p_H value of 3.3, which has involved the death of the plant.

rable alteration of the reaction might have taken place. As it will appear from the sand culture experiments made by me, a considerable alteration of the hydrogen ion concentration of the nutrient liquid takes place where ammonia salts are used as nitrogen

Table 41. The weight (g) of the plants developed in nutrient liquids the hydrogen ion concentration of which was kept constant.

	NH_4Cl	NaN_3O
Tussilagn farfarus (1 plant), fresh.	58.0	06.0
— — (1 —), dry	6.5	6.3
Deschampsia flexuosa (10 plants), fresh	6.0	6.1
— — (10 —), dry	1.0	1.0

fertilizer for plants while these are quite young, but this alteration at the beginning only is quite local, viz. in the liquid in the immediate surroundings of the roots and therefore may become very important.

The seeond argument stated by Söderbaum is, that ammonia nitrate also has a toxic effect, and this salt is according to Söderbaum "physiologically neutral". That ammonia nitrate, however, is physiologically acid will be seen from the experiments made by me. When finally Söderbaum as a third argument states that at his experiments he mixed the soil with bone-dust containing sufficient calcium carbonate to neutralize the acid, that might possibly be liberated at the consumption of nitrogen of the plants, I want to observe that the sandy soil used by Söderbaum beforehand might have been acid, and the calcium carbonate has then been neutralized by the acid found in the soil.

When ammonia chloride at Söderbaum's experiments was the ammonia salt which was most unfavourable to barley plants, while ammonia sulphate and ammonia phosphate had a better effect, it may be due to the fact that the plants of the two last-mentioned salts can use both the acid and the base, while for the greater part they only absorb the base of the ammonia chloride.

Besides it must be noted that when the effects of the ammonia salts at my first experiments were so great that the alkaline soil plants were killed, which was not the case at Söderbaum's experiments, this is essentially due to my cultures not containing buffer. Söderbaum used soil, and soil contains considerable quantites of buffer; furthermore a part of the ammonia nitrogen may have undergone nitrification before being absorbed by the plants.

Söderbaum states that the wheat and barley plants fertilized with ammonia salts contained an abnormally great quantity of nitrogen contrary to the plants fertilized with nitrate of soda.

In order to examine whether the same held good of the plants used for my experiments, I determined the nitrogen percentage [1] in some of the Tussilago plants used at the above described experiments. Only the leaves were analized. Normally these leaves contain about 2.26 per cent of nitrogen [2]. The plants from the sand culture experiments in which the hydrogen ion concentration of

[1] Reckoned on the dry substance.

[2] The normal contents of nitrogen of the leaves was determined by analizing leaves taken on different localities in Nature. The contents of nitrogen varied from 2.0—2.35 per cent. The average contents of nitrogen of leaves from 10 different localities was 2.26 per cent.

the nutrient liquid was kept constant, because calcium carbonate was mixed with the sand, contained after having got ammonia chloride 2.35 per cent of nitrogen in the leaves, and after having got sodium nitrate 2.32 per cent, thus in both cases nearly the normal contents of nitrogen. The plants on the other hand from the sand cultures to which ammonia nitrate had been added and in which the hydrogen ion concentration was not kept constant, why the plants finally died, contained 3.28 per cent of nitrogen in the leaves, thus an abnormally great quantity of nitrogen[1]).

Of course it is not possible with certainty to state the reason hereof, but perhaps it may be explained in the following manner: When the hydrogen ion concentration of the nutrient liquid on account of the absorbtion of ammonia of the plant increases to a value that is critical for the plant, a part of the acid of the nutrient liquid which has been liberated penetrates into the cellular juice of the plant, and consequently the hydrogen ion concentration of the cellular juice increases. To counterbalance this effect, the plant absorbs more ammonia which is used to neutralize the acids. Thus the hydrogen ion concentration of the nutrient liquid further increases, more acid penetrates, and the plant, therefore, must absorb ammonia and so on. In this way a considerable quantity of ammonia is accumulated in the plant.

That the hydrogen ion concentration of the cellular juice really increases when the plants grow under such conditions may be pointed out by aid of litmoid paper. In Tussilago the hyhydrogen ion concentration of the leaf juice under normal conditions has a value of about 6.2[2]), expressed in p_H, but in plants that have developed in sand culture with ammonia nitrate as source of nitrogen as described at the experiments on page 123—130, the p_H value of the juice was found to be 4.8 a short time before the plants began to fade. The plants, on the other hand, that had developed with sodium nitrate as source of ni-

[1]) Tussilago plants, on the other hand, which were cultivated in sand that daily was watered with a nutrient solution only containing nitrogen as nitrate and which was so acid, that the growth of the plants was checked, contained 2.30 per cent of nitrogen in the leaves, i. e. the normal quantity.

[2]) The p_H value of the juice in plants from very different localities in Nature was found to vary from 6.1—6.3 (measured both electrometrically and with lacmoide paper).

trogen showed the p_H value (about 6.2), which is normal for the cellular juice.

The ability of the plants to alter the hydrogen ion concentration of the nutrient liquid.

It appears from the experiments described above that the plants can alter the hydrogen ion concentration of a nutrient liquid, and that the direction in which the alteration takes place depends on the nature of the source of nitrogen. In order closer to examine the question a number of species were cultivated in water culture during the summer 1919 partly with ammonia chloride and partly with sodium nitrate as source of nitrogen. The plants which were used for these experiments were *Deschampsia flexuosa*, *Senecio silvaticus*, *Tussilago farfarus* and *Koeleria pyramidata* as also the culture plants *Secale cereale*, *Triticum sativum* *Avena sativa*, *Hordeum distichum*, *Lupinus luteus*, *Fagopyrum sagittatum* and *Medicago sativa*. At the experiments solution *a* mentioned on page 132 was used as nutrient liquid containing ammonia chloride, and solution *b* mentioned on the same page as nutrient liquid containing nitrate. A mixture of equal parts of the solution *a* and *b* was used as nutrient liquid containing ammonia nitrate.

The p_H values of the solutions were originally 5.6. The cultures were cultivated in duplicate. During the cultivation a constant current of atmospheric air was conducted through the nutrient liquids, so that the carbonic acid liberated at the respiration was driven off[1]).

[1]) In a single case *Deschampsia flexuosa* was cultivated in a nutrient solution with ammonia chloride as source of nitrogen no airing taking place. The hydrogen ion concentration of the nutrient solution gradually increased, but it increased more in the liquid round the roots of the plants than in the other nutrient liquid. For when the plant was taken out of the liquid, the liquid dropping from the roots appeared to be much more acid than the liquid in the glass. The difference was not equalized after the plants having been placed in the glass again, and this had been shaken some times. Not until the glass was shaken energetically for a long time I succeeded in having the hydrogen ion concentration homogeneous throughout the liquid. Such a case, however, certainly only occurs when cultivating a plant that as *Deschampsia flexuosa* has a bulky bunch of fibrous roots hanging in the middle of the liquid embosoming part of the nutrient liquid. When constant airing of the liquid takes place, the hydrogen ion concentration on the other hand always was homogenous throughout the liquid.

In the solutions in which ammonia chloride and ammonia nitrate respectively was the source of nitrogen, the hydrogen ion concentration increased as the plants grew until the value critical for each single species was reached, after which the plants died. The critical hydrogen ion concentration occurred in the nutrient liquids containing ammonia chloride at an earlier time that in those containing ammonia nitrate. The highest hydrogen ion concentration produced by the plants in the nutrient liquid was colorimetrically measured and is stated in table 42, in which the p_H values are indicated. It will be seen from this table that each single species alters the hydrogen ion concentration of the nutrient liquid to a fixed value and that this value differs for the different species, the acid soil plants altering the hydrogen ion concentration to a higher value than the alkaline soil plants. Rye and oats alter the hydrogen ion concentration to a higher value than barley and wheat, and the conclusion may be drawn that the two first-mentioned cereals can stand a higher hydrogen ion concentration than the two last-mentioned ones.

In solution *b* in which the source of nitrogen was sodium nitrate, the plants altered the hydrogen ion concentration of the nutrient liquid in alkaline direction, by which chlorosis graduallly became a fact. However, it was not possible here to determine the lowest hydrogen ion concentration at which the plant can grow, because the death of the plants did not occur as suddenly as was the case with the experiments described above. The lowest hydrogen ion concentration found in the nutrient liquids cannot be considered as the critical limit, as the hydrogen ion concentration of the liquids continued to decrease also after the plants having died; this was due to the incipient decay of the roots, by which ammonia was formed. On the other hand it was observed that chlorosis began when the hydrogen ion concentration of the liquids had reached a fixed value, different for the different species. Thus *Deschampsia flexuosa*, *Senecio silvaticus* and *Lupinus luteus* became chlorotic already when the nutrient liquid had reached a p_H value of about 6, while the other species did not become chlorotic until the nutrient liquid had reached a p_H value of about 7.2.

In a single case the hydrogen ion concentration of the nutrient liquid fell to a value of 6.2 expressed in p_H.; it did not decrease further. The yellow lupine that grew in this nutrient

liquid became slightly chlorotic, but continued to grow though very slowly. In no case, however, it was observed that the plants could make the hydrogen ion concentration of the nutrient liquid increase, when the source of nitrogen was nitrate. Based on these experiments, the plants therefore cannot be ascribed the ability of regulating themselves the hydrogen ion concentration of the nutrient liquid, as Hoagland (1918, 1919) and Arrhenius (1920) hold. At Hoagland's water culture experiment the plants grew in a nutrient liquid containing nitrate, and the alterations of the hydrogen ion concentration of the liquid in most cases therefore passe in alkaline direction. Hoagland, however, states that in a few cases where the hydrogen ion concentration of the nutrient liquid decreased until a p_H value of 7.4, he observed that the hydrogen ion concentration afterwards increased to a p_H value of 6.8. I have never made such an observation at my experiments[1]). It cannot be said what was the source of nitrogen at Arrhenius' experiments, as he has not said anything of the manner in which they were carried out. Weis (1919) also thinks that the plants to a certain degree can regulate the hydrogen ion concentration of the nutrient liquid. Weis namely cultivated maize in slightly alkaline reacting nutrient liquids. In these liquids the plants were thriving badly until a certain time at which the growth suddenly began to increase. At the same time Weis observed "an interesting shifting in the hydrogen ion concentration", as the p_H value of the nutrient liquids was altered from 7.35 to 5.86. "The solution", Weis says, "was here such that the alteration of the reaction might take place according to the needs of the plants as the source of nitrogen was ammonia nitrate (l. c. p. 268)". Evidently Weis considers ammonia nitrate as physiologically neutral, but as will be seen from my experiments this is not correct. The ammonia nitrate is physiologically acid, and the alteration of the hydrogen ion concentration observed by Weis therefore only could take place in acid direction and would have

[1]) It must be remembered that the greater part of the carbonic acid at my experiments was driven off the nutrient liquide by means of atmospheric air. If the carbonic acid had not been driven off, the hydrogen ion concentration in the nutrient liquids containing nitrate would have been higher than it was found to be. It is an open question whether the plants can regulate the disengagement of carbonic acid and thus act regulating on the hydrogen ion concentration of the nutrient liquid, but it is not very probable.

Table 42. The hydrogen ion concentration of the nutrient solutions expressed in p_H at the time when the plants were dying.

	Source of nitrogen	
	NH_4Cl	NH_4NO_3
	p_H	p_H
Deschampsia flexuosa (experiment 1)	2.2	2.3
— — (— 2)	2.2	2.2
Senecio silvaticus (experiment 1)	2.5	2.6
— — (— 2)	2.6	2.5
Tussilago farfarus (experiment 1)	3.3	3.4
— — (— 2)	3.4	3.4
Koeleria pyramidata (experiment 1)	3.5	3.5
— — (— 2)	3.5	3.5
Secale cereale (experiment 1)	2.6	2.7
— — (— 2)	2.6	2.6
Avena sativa (experiment 1)	2.7	2.8
— — (— 2)	2.8	2.7
Lupinus luteus (experiment 1)	2.8	2.8
— — (— 2)	2.9	2.8
Fagopyrum sagittatum (experiment 1)	3.0	3.1
— — (— 2)	3.1	3.1
Triticum sativum (experiment 1)	3.2	3.2
— — (— 2)	3.2	3.2
Hordeum distichum (experiment 1)	3.4	3.4
— — (— 2)	3.3	3.3
Medicago sativa (experiment 1)	3.4	3.4
— — (— 2)	3.3	3.4

taken place in this direction, also if the nutrient liquid originally had had a p_H value of e. g. 4.5; in this case the hydrogen ion concentration would quickly have involved the death of the plants.

It will appear from the above described experiments made by me that of the physiologically acid solution *a* and the physiologically alkaline solution *b*, a physiologically neutral solution

can be produced by mixing the two solutions in suitable proportion. It was found that a mixture of three volumes of solution *a* and seven volumes of solution *b* was nearly physiologically neutral, for when the plants were cultivated in this solution only insignificant alterations of the hydrogen ion concentration took place, also when the hydrogen ion concentration had a p_H-value unfavourable to the plants[1]).

Thus it will be seen from the experiments that the direction of the alterations produced by the plants in the nutrient liquids is determined by the nature of the source of nitrogen.

As mentioned above (p. 135), *Tussilago* plants cultivated in sand culture with ammonia nitrate as source of nitrogen contained an abnormally great quantity of nitrogen when the hydrogen ion concentration critical for the plants occurred in the nutrient liquid. It was also the case at the experiments described here, as *Tussilago* plants from the nutrient liquids containing ammonia nitrate contained 3.52 per cent of nitrogen, the plants from the nutrient liquids containing ammonia chloride 3.58 per cent, while the plants from those containing sodium nitrate contained 2.41 per cent.

Plants of the yellow lupine and buckwheat taken from the same experiment were also analized. Plants of yellow lupine from the nutrient liquids containing ammonia chloride appeared to contain 4.92 per cent of nitrogen, while plants of the same species from those containing sodium nitrate contained 3.36 per cent; buck-wheat plants from the liquids containing ammonia chloride contained 5.63 per cent of nitrogen and the plants from those containing sodium nitrate 1.93 per cent.

Finally it appeared from the same experiments — as was also the case with the experiments described on p. 136 — that plants cultivated in the nutrient liquids containing ammonia chloride and ammonia nitrate when the critical hydrogen ion concentration occured in the nutrient liquid, showed a hydrogen ion concentration of the cellular juice that was higher than normal for the plants.

That the hydrogen ion concentration of the cellular juice may be altered in the direction of the hydrogen ion concentra-

[1]) At the experiments described at p. 113 the nutrient liquid therefore had just the same composition as the said mixture of solution *a* and *b*.

tion[1]) of the nutrient liquid, also when the plants grow in solutions the hydrogen ion concentration of which is considerably lower than that at which the plant reached its most vigorous growth, was shown with regard to *Senecio silvaticus*. The highly chlorotic individuals of this species growing in solution *b*, the p_H value of which at the time when the plants were examined was 6.5, showed a p_H value of 6.2 for the leaves and the stalks, while the cellular juice of normal individuals of *Senecio silvaticus* from Grib Forest had a p_H value of 5.5.

Are aluminum ions toxic to alkaline soil plants?

Hartwell and Pember hold — as mentioned on p. 12 — that they have shown that aluminum ions have a toxic effect on barley but not on rye. This observation has made the two investigators see the "lime-question" in an essentially different light than was hitherto the case, as they consider lime-loving plants (alkaline soil plants), under which barley must be subsumed, as plants to which aluminum ions are toxic, and which consequently cannot thrive in very acid soils, in which always are found small quantities of aluminum in solution, while the species which as rye are thriving comparatively well in very acid soils are not affected by aluminum ions.

That aluminum salts in solution even in small qnantities have a restrictive influence on the growth of the different species in water culture as also in sand culture has furthermore been shown by Hébert (1907), House and Gies (1905), Kratzmann (1914), Ruprecht (1915), Stoklasa (1918 II) and Mirasol (1920)[2]).

[1]) Haas (1920) states that the hydrogen ion concentration of the cellular juice decreases (about 0.1—0.3 in p_H.) when calcium carbonate is added to the soil in which the plants grow. Clevenger (1919) has made the same observations as regards the root juice, but he states that with regard to the overground parts of the plants he had observed an increase of the hydrogen ion concentration of the cellular juice. Hoagland (1919 II) was unable to note on barley plants cultivated in nutrient liquids of different hydrogen ion concentrations, that the hydrogen ion concentration of the cellular juice was affected by that of the growing medium.

[2]) Stoklasa (1918 I) has examined the occurrence of aluminum in a number of plants and found, that hygrophile plants contained much aluminum especially in the roots. Thus aluminum forms 3 per cent of the dry substance in the roots of *Scirpus maritimus;* also *Rumex maritimus* and many cyperacees contain ample quantities hereof; mesophytes contain less, *Tussilago farfarus*

It must, however, be remembered that aluminum salts are very hydrolized, consequently they give a very acid reaction. Thus addition of aluminum salts to nutrient liquids will cause the hydrogen ion concentration to increase, and the toxic effect may therefore be due to a too high hydrogen ion concentration in the nutrient liquid. Miyake thought this possible, and therefore examined the question more closely. He found that the toxic effect of aluminum chloride on rice plants in water culture manifested itself when the concentration was greater than $^n/_{7500}$. A solution of hydrochloric acid of corresponding normality had a corresponding toxic effect, but as the latter had a much higher hydrogen ion concentration than the corresponding aluminum chloride solution, Miyake draw the conclusion that it is not the hydrogen ions originating with the hydrolosis of the aluminum salt, that has the toxic effect on the plants but the aluminum ions themselves.

The experiments hitherto made on the toxicity of the aluminum, however, are not satisfactory, and it cannot be said to be proved that aluminum ions exercise toxic effects on the plants, for i. a. the hydrogen ion concentration of the nutrient liquids and the possible alterations produced by the plants during the growth have not been controlled. It is also admitted by Hartwell and Pember that the experiments must be made at constant hydrogen ion concentration before any certain conclusion can be drawn. Furthermore it must be remembered that aluminum ions more or less completely precipitate the phosphoric acid in the nutrient liquid, consequently the plants may be in want of phosphoric acid, in which case the growth of the plants of course is checked, but this obviously is not due to the aluminum ions. In order to avoid precipitation hereof, Hartwell, and Pember at their experiments have used a very small quantity of phosphate, viz. only about 10 mg KH_2PO_4 in one litre of nutrient liquid. If an essential part of the quantity of phos-

thus 0.5 per cent, while xerophytes are poorest on this substance, as generally they only contain about 0.01 per cent of aluminum. Water culture experiments made by Stoklasa (1918 II) in conformity herewith gave the result that xerophytes were very susceptible to aluminum compounds, while the hygrophile plants were not checked in their growth until far higher hydrogen ion concentrations were reached. Very small quantities of aluminum even had a stimulating effect on the growth of these plants.

phate which beforehand is very small is precipitated by aluminum ions, the plants will suffer from want of phosphoric acid, especially — as was the case at the experiments of the two above mentioned investigators — as 6 barley plants were cultivated in only 250 cc of nutrient liquid.

In order to try the theory set up by Hartwell and Pember I made a number of experiments with *Secale cereale* and *Hordeum distichum* as also with *Senecio silvaticus* and the alkaline soil plants *Tussilago farfarus* and *Koeleria pyramidata*. According to the theory of the said two investigators, aluminum ions are said to be especially toxic to the two latter species.

Previous to the final experiments, a number of experiments were made with rye and barley (Tystofte Chevalier barley); for these experiments a nutrient liquid was made which in one litre boiled and filtered tap water contained:

1.12 g $NaNO_3$
0.30 - NH_4Cl
0.25 - $CaSO_4, 2H_2O$
0.12 - $MgSO_4, 7H_2O$
0.20 - KCl
0.01 - KH_2PO_4
0.003- $FeCl_3$

This nutrient liquid is almost physiologically neutral and contains only a small quantity of phosphoric acid as was also the case with that used by Hartwell and Pember. The two cereals were cultivated in this nutrient liquid at three different hydrogen ion concentrations (p_H 3.5, 4.5 and 6.0) partly with, partly without aluminum, 10 cm^3 0.1 n of dissolved alun[1]) in the experiments in which the plants were cultivated with aluminum were added to 1 litre of the nutrient liquid, which gives 9 mg aluminum on each litre[2]). It appeared that both rye and barley at all the three said hydrogen ion concentrations only showed a poor growth, when aluminum was found in the nutrient liquid, while they were thriving normally when this was not the case[3]).

[1]) This solution contained 15.8 g alun per litre.

[2]) The quantity of aluminum used is somewhat greater than that used at Hartwell and Pember's experiments. At some of my experiments larger quantities (upto 10 times as much) were added, but this did not affect the development of the plants otherwise than the smaller quantities.

[3]) In the solutions the p_H value of which was 3.5 the barley would not deve-

In the solutions containing aluminum and the p_H value of which was 4.5 rye and barley, however, behaved somewhat differently, as the barley after being placed in the aluminous nutrient liquid did not develop new adventious roots, while rye developed several new roots, but besides, as mentioned above, the growth as regards both species was poorer than in the non-aluminous nutrient liquid of the same hydrogen ion concentration. That the plants showed a poorer growth in the aluminous nutrient liquids than in the non-aluminous ones may, however, be due to want of phosphoric acid, for although a very small quantity of phosphoric acid[1]) was found in the above described nutrient liquid, precipitate[2]) appeared when the alun-solution was added, which appeared to consist of phosphate of aluminum. The quantity of the deposit depended on the hydrogen ion concentration of the nutrient liquid, the precipitate being smallest in the most acid nutrient liquid (p_H 3.5), greatest in the least acid one (p_H 6.0). In order to examine how great a part of the phosphoric acid was precipitated of the said quantity of alun (10 cm^3 0.1 n alun solution on each litre), the three solutions the p_H values of which after having added alun were 3.5, 4.5 and 6.0 respectively, were filtered and the quantity of phosphoric acid was determined in the filtrate according to the method of Neumann and Gregersen (Gregersen 1907). In the nutrient liquid the p_H value of which was 3.5, 2.47 mg PO_4 on each litre was found in the filtrate corresponding to 3.53 mg KH_2PO_4 (10 mg added); in the solution the p_H value of which was 4.5, 0.38 mg PO_4 was found corresponding to 0.54 mg KH_2PO_4; in the latter nutrient liquid thus only about $^1/_{20}$th of the original quantity of phosphoric acid solution that had been added was found. In the solution the p_H

lop at all, because this species, as will be seen from the above mentioned experiments, cannot thrive in solutions of so high hydrogen concentration.

[1]) At a number of experiments made in 1918 with the same two species a nutrient liquid containing a great quantity of phosphoric acid was used; at these experiments no difference in the growth of the plants appeared, whether the nutrient liquid contained dissolved alun or not, and the reason hereof obviously was that the aluminum was precipitated by the phosphoric acid.

[2]) This is also the case with the nutrient liquid used by Hartwell and Pember, which I have reproduced. The precipitate in this nutrient liquid is — it is true — not directly visible, as on account of the insignificant salt-concentration of the solution it does not flock out. But if a little sodium chloride is added, the deposit is immediately flocking out.

value of which wos 6.0, the quantity of phosphoric acid was so small as not to allow a determination in one litre of the filtrate.

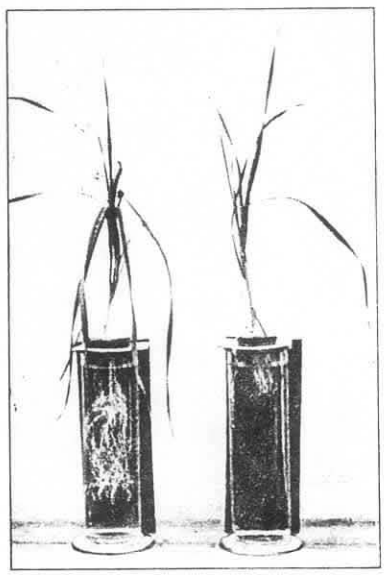
In the said provisionary experiment the quantity of phosphoric acid thus was not the same in the aluminous as in the non-aluminious nutrient liquids, and the poorer development of the plants that has been noted in the aluminous liquids therefore may as well be supposed to be due to want of phosphoric acid as to the presence of the aluminum ions.

At the final experiments the nutrient liquids therefore were composed in such a way that the same quantity of phosphoric acid in solution was found in both the aluminous nutrient liquids as in the non-aluminous ones. Nutrient liquids were used, the p_H values of which were 3.5 and 4.5 respectively, and the aluminous liquids were made in quite the same manner as for the provisional experiment, viz. by adding 10 cm^3 0.1 n dissolved alun to one litre of the nutrient liquid that was composed as that described on p. 144; by means of hydrochloric acid or sodium hydroxyde the solution was then given the desired hydrogen ion concentration. The non-aluminous nutrient liquid also had the same composition as that described on p. 144 except of course as regards the quantity of phosphoric acid, as the nutrient

Table 43. The weight (g) of the plants at the end of the experiment.

	p_H 3.5		p_H 4.5	
	without Al.	with Al.	without Al.	with Al.
Senecio silvaticus (1 plant), fresh . .	10.00	10.50	14.40	14.30
— — (1 —), dry. . .	1.50	1.53	2.00	2.15
Secale cereale (1 plant), fresh	2.80	2.90	4.00	3.80
— — (1 —), dry.	0.31	0.33	0.48	0.47
Hordeum distichum (1 plant), fresh.	»	»	5.30	3.15
— — (1 —), dry. .	»	»	0.71	0.42
Tussilago farfarus (1 plant), fresh. .	»	»	4.23	4.40
— — (1 —), dry. . .	»	»	0.52	0.55
Koeleria pyramidata (5 plants), fresh.	»	»	3.05	3.12
— — (5 —), dry. .	»	»	0.39	0.40

liquid, the p_H value of which was 3.5, contained 3.53 mg and the nutrient liquid the p_H value of which was 4.5, 0.54 mg primary potassium phosphate on one litre (the quantities found at the analysis described on p. 145). The quantity of phosphoric



Without Al. With Al.

Fig. 27. *Hordeum distichum* in water culture without and with aluminum respectively. Note the defective development of the root in the aluminous nutrient liquid.

acid in these nutrient liquids thus was the same as that found in solution in the corresponding aluminous nutrient liquids. As only very small quantities of phosphoric acid were found in all the nutrient liquids, these were changed during the period of the experiment to prevent the plants from suffering from want of phosphoric acid. At the beginning they were changed every second day, later when the plants began to grow quicker, every day. By thus frequently changing the nutrient liquid, the plants did not get opportunity to alter the hydrogen ion concentration.

Senecio silvaticus and rye were cultivated both in nutrient liquids the p_H values of which were 3.5 and 4.5 respectively, the other species on the other hand only in nutrient liquids the p_H value of which was 4.5, as these species cannot develop at much higher hydrogen ion concentrations.

The experiments were commenced on the 18th of June and lasted to the 30th of July. The weight of the plants at the end of the experiment will appear from table 43. It will be seen from this table that barley plants are highly checked in their growth, if the nutrient liquid contains aluminum ions and p_H at the same time has a value of 4.5. In the aluminous nutrient liquid the barley plants did not develop any new adventitious roots, a fact that will be seen from fig. 27. Thus aluminum ions have a restrictive influence on the development of the roots of barley; therefore it must be laid down that aluminum ions really have a toxic effect on barley. Regarding the other species no checking of the development of the root was observed in the nutrient liquids containing aluminum, and it will be seen from the table that the plants reached the same weight, whether they grew in aluminous or non-aluminous nutrient liquids. According to the theory of Hartwell and Pember, aluminum ions are supposed to be especially toxic to alkaline soil plants, but as will appear from the experiment, aluminum ions have no toxic effect on the alkaline soil plants *Tussilago farfarus* and *Koeleria pyramidata*. Therefore, it does not in general hold good that alkaline soil plants cannot thrive in very acid soils, because small quantities of dissolved aluminum compounds are found in such soils.

CLOSING REMARKS.

As shown in section A, the composition of the vegetation varies under natural conditions regularly with the hydrogen ion concentration of the soil. In conformity herewith the experiments described in section B have shown that the plants found in Nature especially in acid soils, the acid soil plants, reach their best growth in nutrient liquids that are considerably more acid than the liquids in which the plant especially found in Nature in slightly acid, neutral and alkaline soil, the alkaline soil plants, reach their best growth. Furthermore the experiments have shown, that alkaline soil plants cannot develop in nutrient liquids of as high hydrogen ion concentration as the acid soil plants, while the latter in the slightly acid nutrient liquids, in which the alkaline soil plants reach their best growth, become chlorotic and only reach a poor growth.

As to the significance for the plant distribution, that possibly might be attributed to two of the factors that vary more or less regularly with the hydrogen ion concentration, viz, 1) the contents of the soil of dissolved aluminum compounds and 2) the course of the transformation processes of the nitrogen the conclusion may be drawn from the culture experiments described in section B, thas it is not the contents of dissolved aluminum compounds in the very acid soils, nor their weak or wanting nitrification, that is the reason of the alkaline soil plants not thriving in these soils, for aluminum ions are not toxic to alkaline soil plants in general, and ammonia salts and nitrates have the same value as source of nitrogen both for alkaline soil plants as for acid soil plants[1]).

[1]) On the other hand the physiologically acid reaction of the ammonia salts can certainly assert itself in the very acid non-nitrificating but ammonia forming soils (raw humus soils), as the hydrogen ion concentration of the soil liquid in the immediate vicinity of the plant roots increases, when the plants absorb the ammonia. In the raw humus soils the hydrogen ion concentration of the soil liquid in the immediate vicinity of the plant roots therefore without doubt can be considerably higher than in the other parts of the soil. The culture experiments have also shown that a raw humus soil plant as *Deschampsia flexuosa* can thrive in nutrient liquids of a considerably higher

The investigations and experiments made therefore make it highly probable that it is the hydrogen ion concentration of the soil as such that has an essential influence on the composition of the plant formations.

Resumé.

The hydrogen ion concentration in natural Danish soils varies from 3.4—8.0 expressed in p_H.

The hydrogen ion concentration of the soil has appeared to have an essential influence on the composition of the plant formations, as the single species only are found in soils, the hydrogen ion concentration of which lies within a certain range characteristic for each single species. Within this range is a narrower range, in which the species has its greatest average frequency.

When the formations are not too poor on species, we can conclude from the composition of the vegetation to the hydrogen ion concentration of the soil.

The number of the species and their density are on an average greatest in soils, the hydrogen ion concentration of which is near the neutral point; by the increasing hydrogen ion concentration of the soil both the number of the species as their density generally decrease.

At a number of water culture experiments it appeared that species, which in Nature only are found on very acid soil (acid soil plants) reached their best growth in nutrient solutions, the p_H values of which were near 4, while species that in Nature only are found on slightly acid, neutral and alkaline soil (alkaline soil plants) reached their most vigorous growth in nutrient liquids the p_H values of which were lying between 6 and 7. In the slightly acid nutrient solutions, in which alkaline soil plants reached their best growth, the acid soil plants did not thrive well and became chlorotic. A graphic reproduction of the conditions of growth will be seen in fig. 14, p. 116.

The theory set up by Hartwell and Pember, according to which the wanting ability of the alkaline soil plants to thrive

hydrogen ion concentration than the soil liquid, which by means of a hydraulic press may be pressed out of a raw humus soil, and which in general has a p_H value of about 3.5.

in very acid soils, is not due to these plants not being able to stand as high hydrogen ion concentrations as the acid soil plants, but on the other hand is due to small quantities of dissolved aluminum compounds being found in the very acid soils, which are said to be toxic to alkaline soil plants but not to acid soil plants, has shown not to be of general validity, as experiments have proved that aluminum ions are not toxic to alkaline soil plants in general.

The theory advanced by Bear and other investigators that acid soil plants are plants that are able to use ammonia nitrogen while alkaline soil plants demand nitrate nitrogen, and therefore cannot thrive in very acid soils, in which the nitrification is poor or wanting, is not correct, as experiments have proved that ammonia nitrogen and nitrate nitrogen are of the same value as source of nitrogen both for acid soil plants and alkaline soil plants.

It furthermore appears from the investigations, that the quantity of plant nutrients of the soil which by some investigators are considered partly to depend on the hydrogen ion concentration of the soil, as the acid soils are considered to be poor on plant nutrients, the neutral, and alkaline soils to be rich on these nutrients, does not to any greater extent influence the plant distribution. It also appeared that there are alkaline soils which are poor on nutrients, and their vegetation shows no resemblance to the vegetation of the very acid soils which are poor on nutrients.

Therefore it is probable that it is the hydrogen ion concentration of the soil as such which exercises an considerable influence on the composition of the vegetation.

The soil analysis and culture experiments described in this treatise are carried out in the Chemical Department of the Carlsberg Laboratory, where I have worked as a guest, until on the 1st of June 1919 I was appointed assistant there. I convey my best thanks to Professor S. P. L. Sørensen, D. Sc. and Director of the Laboratory for the readiness with which I was given access to the Laboratory to work there with my experiments. I am also very beholden to him and Professor C. Raunkiær, my university professor at botannics for the interest, with which they

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